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VEHICLE CROSS-COUNTRY MOBILITY

John D. Shotter
Earl S. Brown

U. S. ARMY TRANSPORTATION COMBAT DEVELOPMENT GROUP
Fort Eustis, Virginia

A

SUMMARY

VEHICLE CROSS-COUNTRY MOBILITY

(Project CD 500-5-57)

1. PURPOSE AND SCOPE. This study considers the requirements necessary to determine a practical definition and measure of degree of cross-country mobility required in vehicles for the Transportation Corps motor transport fleet in the long range period.

2. DISCUSSION.

a. There is a requirement for immediate and continued improvement in the ability of transport vehicles to operate off the road in order to attain and maintain parity of movement with the tactical elements of the modern Army. In recognition of this need, the Chief of Transportation, in 1956, stated that it is imperative that the Transportation Corps determine and establish a practical definition and measure of the degree of cross-country mobility required; this being a positive prerequisite to the preparation of realistic vehicle military characteristics and a properly oriented research and development program. 1/

b. The ever increasing requirement for greater Army mobility in all environments dictates that the Transportation Corps emphasize development of cargo carrying equipment which can keep pace with whatever movement is required in resupply operations. In the time frame of this study (1965-1970), it is estimated that an integrated transportation system utilizing air, rail and motor transport will be employed. Rail potential in the LOC will be limited by the zone of operation, the state of the road bed, the organization, and the availability of equipment. Operational continuity and flexibility of movement most probably will be achieved by means of surface motor transport possessing both on-road and cross-country capabilities. If we are to have this capability, there must be rapid and drastic improvement in the mobility characteristics of the Transportation Corps organic vehicles, resulting in equipment capable of responding with speed and agility to the combat units requirements in both logistical and tactical situations.

3. PRINCIPAL CONCLUSIONS AND RECOMMENDATIONS.

a. This study concludes, in general, that the degree of cross-country mobility required for vehicles of the motor transport fleet is measured in terms of the specific performance characteristics of the most mobile major vehicles in the combat units supported; and that the present Transportation Corps transport vehicles are not capable of off-road movement commensurate with the requirements of cross-country mobility throughout the Army operational areas of future employment.

1/ Ltr, OCOFT, TCMTD-E, RCS 18, 19 Oct 1956, "Vehicle Cross-Country Mobility Definition and TC Requirement, 1960-1970 Army."

b. It establishes optimum cross-country mobility performance characteristics for vehicles of the Transportation Corps motor transport fleet, carrying rated load in the temperate areas of the world, under average seasonal conditions and variations; and outlines specific features of a test course whereby these characteristics can be effectively checked in vehicle prototypes.

c. The study recommends adoption of the optimum vehicle performance characteristics for cross-country operations, as constituting a practical definition of the cross-country mobility required in vehicles of the Transportation Corps motor transport fleet in the long range period; and that the test course features be accepted as a practical method of measuring this mobility.

1. PROBLEM. To determine a practical definition and measure of degree of cross-country mobility required in vehicles for the Transportation Corps motor transport fleet in the long range period.

2. ASSUMPTIONS.

a. A continuing requirement will exist for surface transport capability in the foreseeable future.

b. The present cross-country capabilities of the Transportation motor transport fleet are not adequate for all operational tasks.

3. FACTS BEARING ON THE PROBLEM.

a. For this study period, surface motor vehicles must be considered as one of the most reliably known modes of transportation in support of field army operations.

b. Basic research into the field of measuring vehicle mobility in soft soils has not yet progressed to the point where it has practical application to the problem set forth in this study.

4. DISCUSSION.

a. Introduction.

(1) There is a requirement for immediate and continued improvement in the ability of transport vehicles to operate off the road in order to attain and maintain parity of movement with the tactical elements of the modern Army.

(2) In view of this foreseeable requirement for motor transport equipment with a high degree of cross-country mobility for use in support of the future Army, it is imperative that the Transportation Corps determine and establish a practical definition and measure of the degree of cross-country mobility required. This is a positive prerequisite to the preparation of realistic vehicle military characteristics and a properly oriented Research and Development Program.*

(3) Of the three cardinal modes of transportation employed by the Armed Forces - land, sea, and air - the science of land locomotion is undoubtedly in the most backward state. Since World War I, the state of the art of

*Letter, OCOFT, (TCMTD-E RCS 18), Vehicle Cross-Country Mobility Definition and MC Requirement, 1960-70 Army, 19 Oct 1956.

aerodynamics and hydrodynamics have sped forward far out of proportion to the science of land locomotion, which at this time must be developed to comparable status in order to meet the ever increasing need for integrated transportation systems.

(4) Over the last 50 years, the major effort in the advancement of the science of land locomotion has been devoted to the attainment of speed, capacity and passenger comfort over prepared highways. This devotion of effort applied by the automotive industry to speed and capacity has resulted in probably the most modern system of highways in the world, and made for the economic comfort of the public and the producing industries; however, the salient need of the armed forces is freedom of movement, both over the highway and, in times of need, cross-country.

(5) The rapid advance in the field of atomic firepower and the increase of flight range and accuracy of missiles will shape the strategy and tactics of a future war. Warfare will be characterized by the continual maneuvering of combat units over wide expanses of territory. Offensive operations will consist of rapid strikes at the weakest point of the enemy's defenses to destroy the enemy rather than to hold terrain, with equally rapid withdrawals. Rapid movement will also be vital to defensive operations in order to deceive the enemy with regard to the location of units.

(6) In the time frame under consideration in this study, it is estimated that an integrated transportation system utilizing air, rail and motor transport will be employed. Rail potential in the LOC will be limited by the zone of operation, the state of the road bed, the organization, and the availability of equipment. Also it is expected that a large percentage of the rail capacity will be utilized for support of the indigenous population. Operational continuity and flexibility of movement most probably will be achieved by means of surface motor transport possessing both on-road and cross-country capabilities.

(7) If we are then to depend heavily upon motor transportation in fulfilling the Army support requirements, it will call for a capability that at present is not adequate. If we are to have this capability, there must be rapid and drastic improvement in the mobility characteristics of the Transportation Corps' organic vehicles, resulting in equipment capable of responding with speed and agility

to the combat unit's requirements in both logistical and tactical situations.

(8) In future operations the Transportation Corps will use prepared surfaces wherever available and will resort to movement cross-country when required; however, this requirement for moving cross-country rather than over prepared surfaces in both the combat and logistical support areas will increase rapidly as new weapons and tactics become realities.

b. Concept of Transportation Corps motor vehicle operations:

(1) In order to enable us to select and isolate the indices for future Transportation Corps vehicle mobility, it is necessary to discuss concepts of future Transportation Corps motor vehicle operations.

(2) Mobility requirements in the two main areas of a theater of operations - communications zone and field army - will be considered in order to determine whether, in fact, separate requirements exist for logistical vehicle characteristics in the two zones.

(3) In each of the above general areas there exists a need for intra-area (local) motor transport service units. Subordinate "area" commands, primarily administrative in function, may be contained in either of these main areas; they too would have an intra-area transport capability.

(4) To provide for the inter-area (line haul) service from, to, and through the main operational areas (and subordinate included command structures) there may be established a transportation intersectional motor transport service responsible for controlling and operating a general hauling service comprising a pool of motor vehicles devoted to the "line haul" mission.

(5) The moving "island" concept of operations as envisaged for future wars, wherein land areas devoid of friendly troops may exist between the base section, advance section and field army area, presents an opportunity for enemy infiltration and sabotage which must be considered. Any measure of enemy success in these "voids", the planned defense of the LOC notwithstanding, will create obstacles to the passage of motor vehicles. Destroyed bridges and sections of roadway or contaminated areas can be expected while operating in this area. Intersectional motor vehicles engaged in line haul operations must have cross-

country capabilities to the extent necessary to bypass such temporary obstacles, but not to an extent requiring complete independence of prepared surfaces of any type at all times.

(6) There is every reason to believe that an area sufficiently large and sufficiently important to justify the commitment of a theater Army will contain within it a pattern of roads or trails which are not susceptible to complete destruction, even in this day of mass destruction weapons. It is necessary, therefore, to dispel the belief that motor transport vehicles engaged in line haul operations in future wars must be entirely divorced from visible routes possessing (as a result of prior travel thereon, or deliberate stabilization) some degree of improved surface.

(7) Within the field army area, and particularly from army depot and supply points forward, the requirement for mobility is increasing to the point of requiring that transport vehicles be comparable to tactical vehicles in their ability to operate off of prepared surfaces. Terrain obstacles additional to the natural ones discussed elsewhere in this study are created in this area by direct destruction as opposed to infiltration and sabotage damage encountered along the LOC's. It is in the divisional area, with its dispersed and highly mobile combat groups, that the highest degree of cross-country mobility will be essential.

(8) Furthermore, the combat group area within a division is subjected to the most continuous firepower of the enemy. In this area exists the most demanding requirement for agility of movement on the part of the combat elements, so as to exploit all advantages over the enemy. Here the transport service must be geared to the rapid pace of battle deployment so as to provide adequate logistical support to combat units. In this area can be expected the greatest enemy damage to the existing road net, and the consequent denial of road usage. Hence, the greatest need for true cross-country mobility in motor transport equipment exists in this area.

c. Transportation Corps mobility requirements in the field army area:

(1) The optimum cross-country mobility characteristics for vehicles of the Transportation Corps motor transport fleet in both the field army area and the communications zone can be best expressed in terms of the relationship

between the specific terrain or water obstacles to vehicular movement and the vehicle performance characteristics required to overcome these obstacles.

(2) These environmental obstacles - or "surface movement resistance factors" (as they are henceforth referred to in this study) may be divided into the following categories: (ANNEX A)

(a) Soft soils: Sand, loam, and clay in various combinations and consistencies.

(b) Slopes: Beach slopes, ditches, and river banks as well as hills and mountains.

(c) Rock-covered and wooded areas: Both sparsely covered and closely covered terrain.

(d) Shallow waters: Streams, ponds and canals.

(e) Deep waters: Open expanses, such as lakes, and rivers.

(3) To overcome these resistance factors, improvements in the following "vehicle performance characteristics" areas are needed: (ANNEX B)

(a) The tractional system: To overcome soft soils.

(b) Angles of approach, departure, and break (vertical obstacle negotiability): To overcome beach slopes, ditches, and river banks.

(c) Gradeability and lateral side slope stability: To overcome hills and mountains.

(d) Steering radius and ground clearances: To overcome sparsely covered rocky and wooded areas.

(e) Fordability:* To overcome shallow waters.

(f) Navigability: To overcome deep water.

(4) Chart No. 1 illustrates the surface resistance and related vehicle characteristics. The vehicle performance characteristics needed to overcome the surface resistance factors constitute in effect a definition of the Transportation Corps mobility requirements for the very long range period.

*"Fordability" is stated in terms of its current definition; however, when "Navigability" is achieved, "Fordability" is inherently included.

(5) Transportation Corps vehicles in direct support of combat elements should possess a cross-country capability comparable to that of the major tactical vehicle found within the element supported. Therefore, before determining the cross-country mobility requirements for Transportation Corps vehicles in the field army area, it is first necessary to determine the specific performance characteristics of the most mobile major tactical vehicles in the combat units supported. Measurement of the cross-country capabilities of the transportation vehicle involves comparing its ability to overcome the surface resistance factors named above with the ability of the tactical vehicle to overcome the same factor.

(6) The M-59 armored personnel carrier and the M-48 tank appear to be the most mobile major vehicles organic to the current division, so that their performance characteristics in overcoming various surface resistance factors have in general been established as the minimum requirements for the Transportation Corps vehicles that will be employed in direct support activities. Possible future replacements for these vehicles are under development and their anticipated characteristics have also been considered in this study. A requirement will exist for a logistical vehicle which can keep pace with them, as far as movement across unprepared surface is concerned.

(7) It may be well to note parenthetically at this point that the characteristics of the tank of the future combat division are not firm at the present time. No matter what particular form the future tank assumes, it is almost certain that it will have to possess at least the same cross-country capabilities as the current medium tank. (Chart 2)

(8) In Chart 2, the mobility capabilities of these major combat vehicles become a definition of the minimum capabilities required for the logistical direct support vehicles of the Transportation Corps fleet. If the capabilities of the direct support logistical vehicle to be used in the field army area are to be at least equal to those of the vehicles in question, this Transportation Corps vehicle must have a ground pressure which will permit movement in soft soils comparable to the tactical vehicles. Its angles of approach and departure must be 90°, while its angle of break must enable it to negotiate a vertical change in surface level of 26 inches without bellying. The vehicle must have a 60% gradability for negotiation of hills and mountains. The steering radius of the vehicle must not exceed 23 feet and its ground clearance

CROSS-COUNTRY MOBILITY STUDY

TERRAIN-VEHICLE RELATIONSHIPS

SURFACE MOVEMENT RESISTANCE FACTORS	TYPES	RELATED VEHICLE CHARACTERISTICS
Soft Soils →	Sand) Loam) Clay) in various combinations and consistencies. →	Tractional System (Ground pressure)
Slopes →	Beach slopes Ditches River banks →	Angle of approach Angle of departure Ground clearance
	Hills Mountains	Gradability Lateral side slope stability
Rocky & Wooded Areas →	Sparse woodlands →	Steering radius
	Logged or rock-strewn areas →	Ground clearance
	Dense woodlands →	None (natural barrier)
Shallow Waters →	Streams Ditches →	Fordability
Deep Water →	Open expanses →	Navigability: (Buoyancy) (Stability) (Propulsion) (Steering)
Speed →	Environmental conditions →	Horsepower (Horizontal draw-bar pull)

CHART 1

VEHICLE COMPARISON CHART

	Tank M-48 (present)	Carrier, Pers. Full Tracked M-59	Minimum Criteria for Proposed TC Cross Country Transport Vehicles	Present Transport Vehicles: Truck 2½-Ton M-34	Rating*	Tractor/Trailer M-52/M-127	Rating*
PERFORMANCE, LAND:							
Ground pressure (Floatation) (psi)	10.2	7.1	A ground pressure to permit movement in soft soils comparable to the most mobile major tactical vehicles in the supported units.	35	UN	[illegible]	UN
Angle of Approach (degrees)	90	90	90	40(w/winch) 48(w/o winch)	UN	37(w/winch) 52½(w/o winch)	UN
Angle of Departure (degrees)	90	90	90	43	UN	(est) 45	UN
Angle of Break (Maximum height of vertical obstacle can negotiate at a 90° angle of intersection) (inches)	36	26	26	20	UN	15½	UN
Gradability (percent)	60	60	60	64	S	55	S
Side Slope Lateral Stability (percent)	—	—	Center of Gravity permitting 360° turn on 60% (31 degree) slope	—	NR	—	NR
Steering, Turning radius, outside (feet)	Pivots in place	23	23	35	UN	33	UN
Ground Clearance (inches)	18	18	18	19½	S	11-3/8	UN

CHART 2

VEHICLE COMPARISON CHART (cont'd)

	Tank M-48 (present)	Carrier, Pers. Full Tracked M-59	Minimum Criteria for Proposed TC Cross-Country Transport Vehicles	Present Transport Vehicles: Truck $2\frac{1}{2}$-Ton M-34	Rating*	Tractor/Trailer M-52/M-127	Rating*
Cruising Range (miles)	100	120	300	350	S	300	S
Maximum Land Speed (mph)	30	32	35	62	S	52	S
Fordability (inches)	48	Floatable	Floatable	72	UN	30	UN
PERFORMANCE, WATER: Buoyancy	None	Buoyant	Buoyant	None	NR	None	NR
Minimum freeboard loaded (inches)	None	13	13	None	NR	None	NR
Steering Ability (water)	None	Satis-factory	Positive steering ability in water	None	NR	None	NR
Water Speed (mph)	None	4.3	7	None	NR	None	NR

*Key to Ratings:
UN - Unsatisfactory
S - Satisfactory
NR - New Requirement

CHART 2

must not be less than 18 inches. In Water, it must be buoyant and possess positive steering and propulsion capabilities, and be able to achieve a water speed of seven mph.

(9) Chart 2 also outlines the specific mobility capabilities possessed by both the 2-1/2-ton, M-34 cargo truck, and M-52/M-127 tractor-trailer which are currently in use in both the communications zone and the field army area. A glance at their ground pressure, angles of approach and departure, steering radius etc., as they appear on the chart, should be sufficient to indicate the considerable deficiencies in the mobility capabilities of these vehicles if they are to be used in support of combat units. Improvement must be such that these logistical vehicles possess at least the capabilities specified in paragraph (8).

d. Transportation Corps mobility requirements in the communications zone:

(1) An increase in the cross-country capabilities of Transportation Corps vehicles should not bring in its wake a decrease in the ability of Transportation Corps vehicles to perform on prepared surfaces, with the possible exception of a reduction in "on-road" cruising speed to 35 mph. The minimum reduction in highway performance is acceptable, primarily because present Transportation Corps vehicles, even with their capability for higher cruising speed, very rarely exceed the 35 mph figure in actual operations.

(2) All other on-road characteristics of future Transportation Corps cross-country vehicles would be at least equal to those of the present fleet, therefore, the logistical vehicles to be used in direct support operations in the combat zone should, if considerations of payload are excluded, be equally suitable for use in line haul operations in the communications zone. While movement in this zone may be geared primarily to prepared surfaces, if the future theater of operations is Western Europe or CONUS, it will nevertheless be necessary to leave the road in order to avoid surface disruptions and other obstacles to movement. Although the distances off the road involved in cross-country movement may be less in the COMZ than in the combat area, the surface resistance factors found "off the road" will be strikingly similar, i.e., soft soils, slopes, rocky or hilly terrain, shallow streams, etc.

(3) If the future theater of operations should be the Balkans, Indo-China or other areas with a rudimentary road network and extremely adverse terrain conditions, cross-country vehicle mobility requirements would be the same in both the field army area and the communications zone.

e. Method of measuring Transportation Corps cross-country mobility requirements:

Now that Transportation Corps vehicle cross-country mobility has been defined in terms of vehicle performance characteristics required to overcome specified surface resistances to cross-country movement, it becomes apparent that the method of measurement consists simply of testing the performance of vehicle prototypes against the specified terrain resistances. This can be accomplished in a test area which includes the actual and in some cases simulated cross-country terrain conditions enumerated in the study. Required test course features to check the performance required of the vehicle operational characteristics for fully loaded motor transport vehicles are set forth in Chart 3.

5. CONCLUSIONS.

a. The degree of cross-country mobility required for vehicles of the Transportation Corps motor transport fleet is measured in terms of the specific performance characteristics of the most mobile major tactical vehicles in the combat units supported.

b. The present Transportation Corps motor transport vehicles are not adequate to the requirement for all operational movements in the temperate zone in that:

(1) The combat support vehicles are not capable of cross-country movement comparable to the major tactical vehicles of the combat elements supported.

(2) The present Transportation Corps transport vehicles are not capable of off the road movement commensurate with the requirements for cross-country mobility throughout the army operational areas of future employment.

c. The optimum cross-country mobility performance characteristics for vehicles of the Transportation Corps motor transport fleet, carrying rated load in the temperate areas of the world, under average seasonal conditions and variations, are: (See Charts 4 and 5)

(1) Tractional system (ground pressure) - Adequate to permit continuous movement in soft soils equal to that of the most mobile major tactical vehicles in the unit being supported.

(2) Angle of approach - 90°

(3) Angle of departure - 90°

(4) Angle of break (vertical obstacle clearance) - to enable negotiation of 26" vertical change in running surface without bellying.

(5) Gradability - 60%.

(6) Lateral stability - Center of gravity permitting 360° turn on 60 percent slope (31°).

(7) Steering radius - Not in excess of 23'.

(8) Ground clearance - Not less than 18".

(9) Navigability - Positive buoyancy with adequate level trim freeboard when fully loaded to withstand 12" waves without swamping. Stability sufficient to traverse shallow and deep inland waters under its own steering and propulsion; to attain a water speed of seven mph.

(10) Tractive effort - To maintain continuous forward movement equitable to the environment.

(11) Sustained speed - Capable of sustained cruising speed on a hard surface of not less than 35 mph for 300 miles.

d. The cross-country capabilities of the Transportation Corps motor transport fleet in the long range period should not decrease the performance characteristics (including speed) of these vehicles on prepared surfaces below the acceptable prescribed limits.

e. A test course, with the specific features outlined in Chart 1, is required to check the cross-country mobility of Transportation Corps vehicle prototypes.

6. RECOMMENDATIONS.

a. That the vehicle performance characteristics for cross-country operations as outlined in paragraph 5 c be adopted as a practical definition of the cross-country mobility required in vehicles of the Transportation Corps motor transport fleet in the long range period.

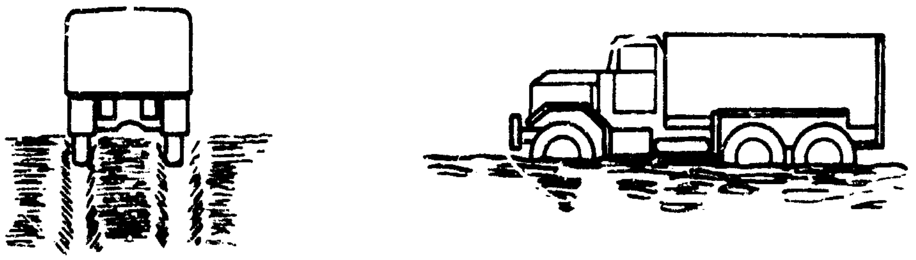
ADDITIONAL TEST COURSE FEATURES FOR MOTOR TRANSPORT VEHICLES WITH RATED LOAD

VEHICLE OPERATIONAL CHARACTERISTIC	PERFORMANCE REQUIRED	REQUIRED TEST COURSE FEATURES
Sustained velocity:		
on road	35 mph minimum	
off road	5 mph minimum	
soft surface	continued movement	Soft soil bed containing viscous plastic soil (clay content) saturated to 22% water; depth greater than ground clearance of tracked vehicles, and equal to the wheel radius of wheeled vehicles.
Gradability	60% minimum (31 degrees)	60% slope, firm surface, sufficient length to permit starting and stopping of vehicle midway, width to permit reversal of direction.
Lateral Stability	360° turn on 60% slope (31 degrees)	"
Turning radius	23 ft. maximum	Simulated stump and boulder strewn field.
Ground clearance	18" minimum	Simulated stump and boulder strewn field.
Angle of Approach	90°	Configurations of surfaces offering abrupt elevation in surface levels equivalent to height of wheel radius.
Angle of Departure	90°	Configurations of surfaces offering abrupt elevation in surface levels equivalent to height of wheel radius.
Water Navigability	Floatable	Body of water with beach gradients up to 60%; depth to permit vehicle to swim & demonstrate speed and steerability.
Freeboard	To withstand 12" wave without swamping vehicle	
Speed	7 mph	
Cruising range	300 miles on land	

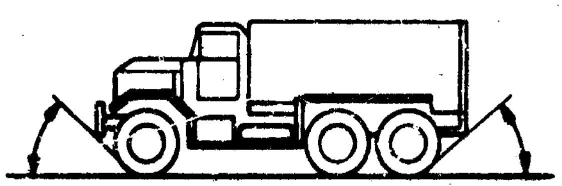
CHART 3

CHART 4

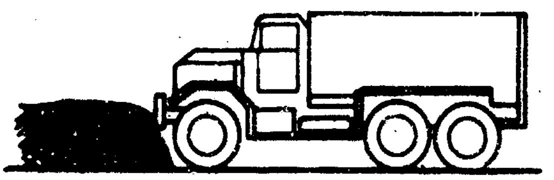
SINKAGE IN SOFT SOILS



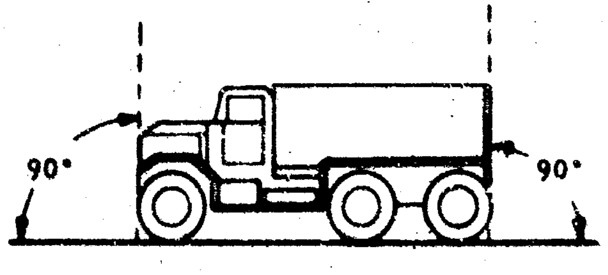
ANGLES OF APPROACH & DEPARTURE



ANGLE OF APPROACH



FUTURE REQUIREMENT:
ANGLES OF APPROACH & DEPARTURE



ANGLE OF BREAK

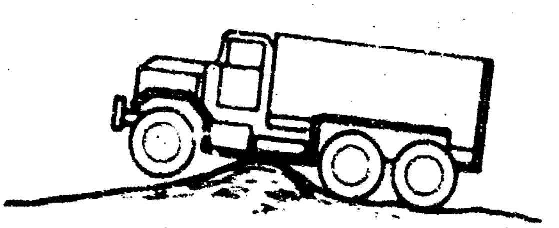
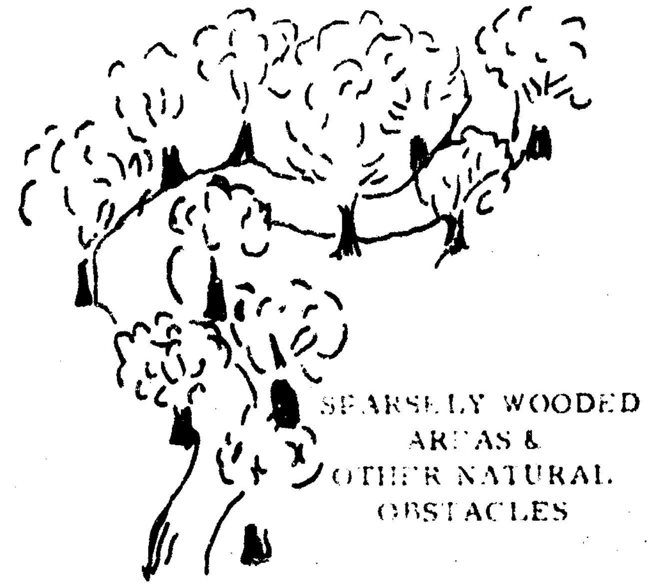
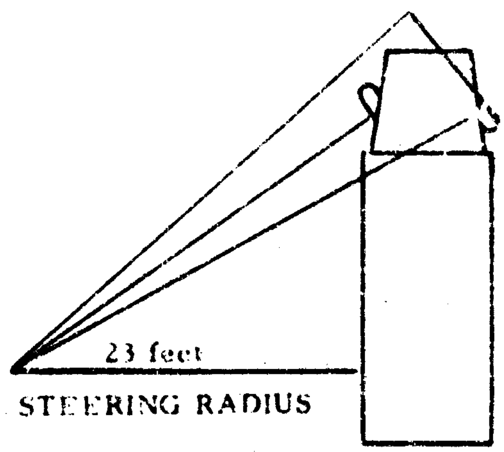
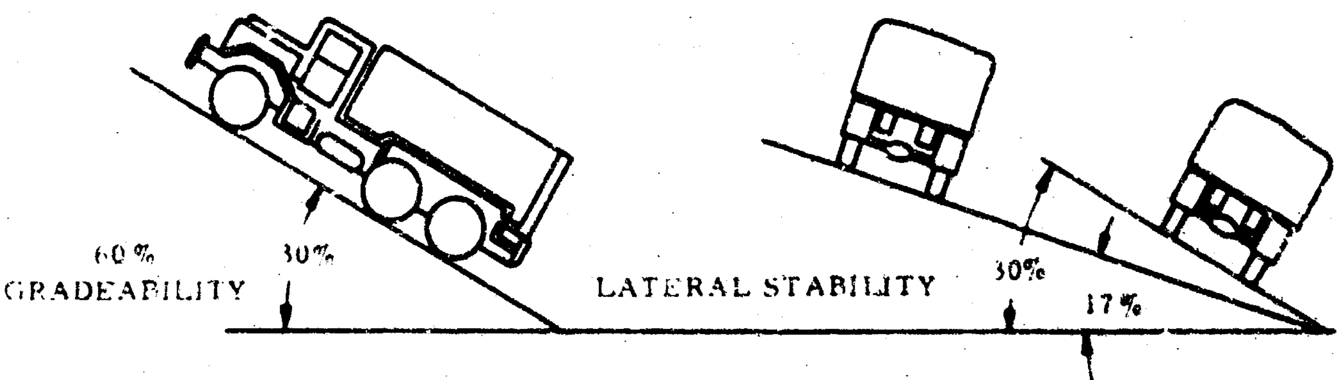


CHART 5







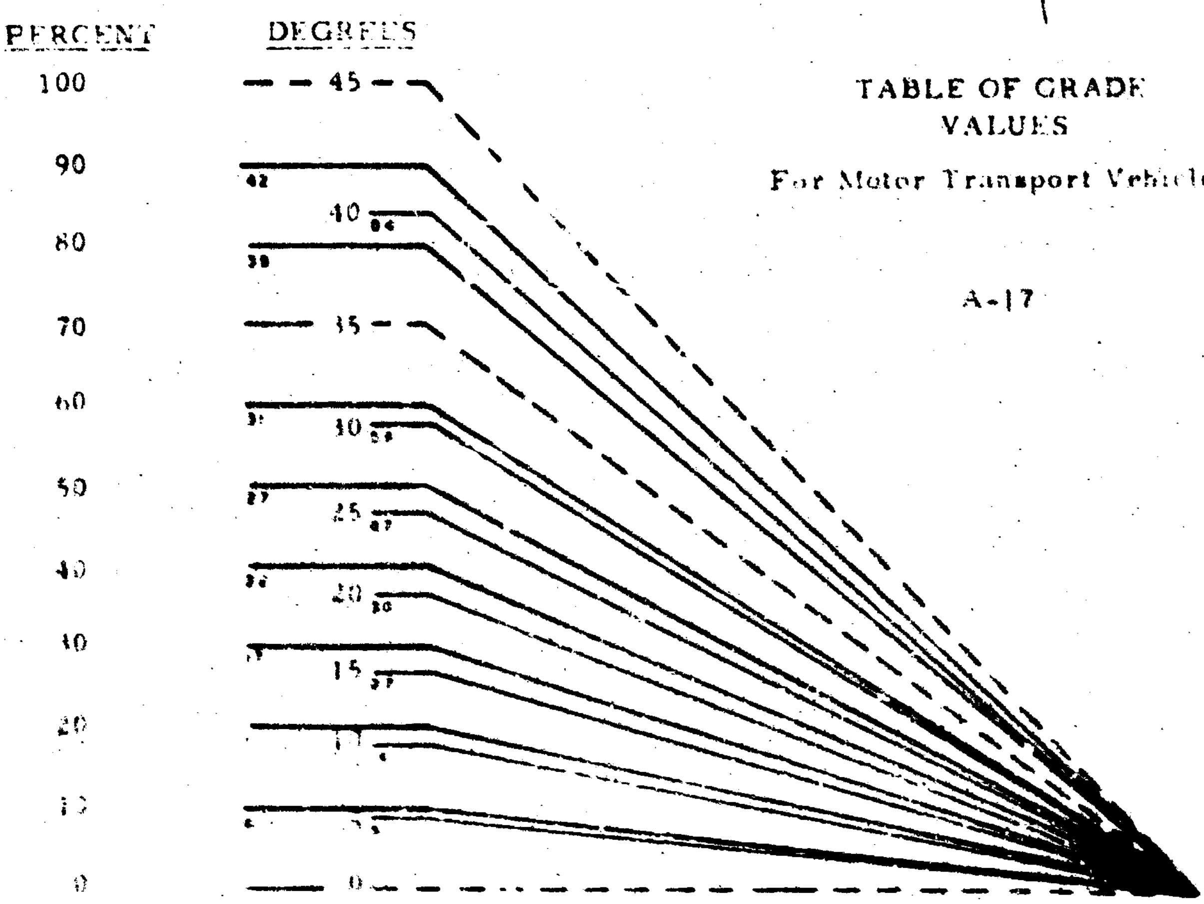


TABLE OF GRADE VALUES

For Motor Transport Vehicles

A-17

b. That the test course features (Chart 3) be adopted as a practical method of measuring cross-country mobility requirements of the Transportation Corps vehicle fleet in the long range period.

c. That the motor vehicle test areas currently in use be modified to the extent necessary to insure inclusion of the test course features established in Chart 3.

ANNEXES: A--Surface Resistance Factors
B--Vehicle Performance Characteristics
C--Summary of Comments

SURFACE RESISTANCE FACTORS

1. Soils

a. In any discussion on vehicular cross-country agility, surface soil constituency, texture, and the state of saturation will prove to have the most important bearing on the outcome.

b. The word "soil" can cover wide latitudes of variance in texture and composition, each in turn having considerable influence on mobility resistance.

c. Depending upon the relative amounts of sand, silt and clay in the soil composition, soil class names are given (for example: clay, clay loam, silt loam, sandy loam, loamy sand and many others far too numerous to mention).

d. Some of these soil properties absorb and retain water to a greater extent than others; hence there is an unending variation of saturated conditions to legislate for in a physical analysis of any one soil. Soil composed of any of the above mentioned properties, when saturated to even a moderate degree, after agitation by surface disturbance can be reduced to a state of emulsion, which is commonly called mud, clay mud or plastic mud, offering the greatest soil resistance factor. There is, of course, no standard depth of mud, but there most certainly is a limit to the depth through which any given vehicle can negotiate.

e. The depth of penetration of the surface soil therefore is the governing factor to mobility and the speed of movement.

f. The broader footprint, least-pressure to the square inch of vehicular tractional weight on the surface of the ground is, therefore, the fundamental aim of future development.

g. One of the most critical soil conditions which frequently occurs is a fluid viscous mud overlaying a hard bottom. Often it becomes necessary for military vehicles to cross such terrain, which is to be found in most areas of the world.

(1) The heading "soft soils" is usually given to the manifold varieties of soils (such as loam, sand, and clay) found on the earth's surface. Clay and the various combinations of soils containing clay, when containing some degree of water content, are classified as plastic or viscous soils.

(2) Since the stability and firmness of the texture of soils vary according to the cohesive force exerted by the molecules of the soil on each other, increasing the water content of any soil texture combined with clay weakens this cohesive force, until a point is reached when the soil is said to be saturated. The result of saturation is a fluid viscous "mud". The depth to which the soil is penetrated with water is, of course, the factor which governs vehicular movement through or across it. There are evident limits to the depth of mud through which vehicles can pass. As a case in point, a wheel in general can only penetrate from one-third to one-half of its diameter before reaching the limit of its forward movement through mud.

(3) Sand, however, acts somewhat in reverse order. It is a special type of "soft soil", by virture of the fact that its grains are segregated, are not molded together by any kind of cohesive force and so are free to move upon each other with ease.

(4) Therefore, unlike clay or clay loam, sand offers the lease resistance to movement when it contains a limited degree of moisture; once this point is reached, however, sand proceeds to offer relative resistance to movement as do clay and loam.

2. Shallow waters.

a Shallow waters, for the purpose of this discussion, are those which can be traversed by a non-floating type vehicle. Generally, those streams or rivers that are shallow enough to permit fording would fall into this category.

b. The fordability of a vehicle is dependent upon several factors. Primarily this term refers to the depth of water through which a vehicle can travel without "drowning out". However, other very important factors are the ability of the vehicle to:

(1) Negotiate the conditions of soil found beneath the water

(2) Negotiate the banks on either side of the water body and,

(3) Negotiate the road, trail, or path leading to the point on the bank where the ford will be attempted.

c. Often when the river or stream is shallow enough to ford, sediment on the bottom mires the vehicle. Therefore, a firm footing permitting the wheels to exert effort is a prerequisite to fording. Without shelf rock or heavy sandy gravel beneath the water, fording of streams becomes risky or impossible.

3. Deep waters.

a. Deep waters, for the purposes of this discussion, are those that cannot be forded and which would necessitate the utilization of floatable vehicles to overcome them.

b. One of the frequently encountered resistance factors to true vehicular cross-country mobility is non-fordable water. Rivers, streams, canals and lakes abound in populated areas in the temperate zones of the world. Very few of the present army vehicles can overcome this type of obstacle with inherent vehicular characteristics.

c. When considering the nature of a river or stream, the conditions of the bank and the current of the water must be taken into account. The banks of active watercourses are seldom gradual, but more often abruptly descend from the land mass to the level of the water. Seasonal floods or low water conditions in a river create various conformities of the banks at different times of the year.

d. Canals create another type hazard; the build-up retaining walls, internal or external to the canal would, many times, require that the vehicle crossing (traversing) it stand on its nose or its tail to wallow in or out of the canal. This same situation would be evident when descending or ascending steep river banks.

e. In order for a vehicle to move to the far side of the body of water under its own power, it must not only float but it must have propulsion apparatus adequately powered to move the vehicle ahead at a reasonable speed to overcome the effects of currents, plus a positive steering capability to permit maneuverability in water.

4. Woodlands.

a. Wooded areas at times present formidable obstacles to vehicular through-movement. Woodlands exist in practically all types of productive soil, varying from the water soaked to the arid rocky types in the temperate zone, and ranging from sea level to thousands of feet high on mountains.

b. Virgin timberland consisting of thick masses of trees, shrubs, undergrowth and fallen timber constitutes an insurmountable obstacle to vehicular movement if cleared pathways through it are not available.

c. "Second growth" forests, in previously logged or "burned-over" land (in the United States), consist of trees and shrubs in varying degrees of density and stages of growth, and in addition, contain the stumps and brushwood of the former forest. Military vehicle movement in this type forest is not very feasible.

d. Reforested land (in the United States) can be assumed to have somewhat of an orderly arrangement of rows of trees. Yet the stumps of previously cut trees are most likely still in existence and considerable underbrush can be expected.

e. On the other hand, a great many of the forests of Germany and France are comparatively free of stumps and undergrowth. In addition, selective logging and systematic planting have tended to reduce the denseness of a great many of the wooded areas. Consequently, movement of vehicles through these forests is less restrictive than through the others previously discussed. Yet such timber stands as are existent in the Black Forest in Germany are impassable except via roadway.

f. We cannot arbitrarily state that wooded areas are always major obstacles, or that the so-called "cross-country" vehicles must be able to traverse all wooded areas.

g. Wheeled vehicles would encounter great difficulty in attempting to traverse stump-studded woodlands, or those in which the trees were close together (and exceeded two or three inches in diameter), unless a cleared pathway were available. Armored tracked vehicles would be only slightly more efficient in moving through such woods.

h. The consistency and moisture content of a soil, either in woodlands or other areas, create another resistance factor to vehicular movement. This will be discussed under the heading of "soils" below.

i. Mobility requirements for vehicles to operate in wooded areas differ from those required of vehicles to negotiate the comparable soil conditions found in non-wooded areas because of the need to straddle small stumps, bypass the taller ones maneuver between the trees, and force a path through shrubs and thickets by knocking down trees of two or three inches in diameter.

j. To expect that a military cargo vehicle should attain <u>true</u> "cross-country mobility" in <u>all</u> wooded areas is not realistic.

5. <u>Rock strewn terrain</u>. Terrain that is studded with rocks and boulders presents a type obstacle similar to that encountered in stump-studded areas and so must be overcome by the same type vehicle characteristics. Suitable ground clearance to overpass the obstacle or sufficient steering dexterity to permit maneuvering around these obstacles would be essential.

6. <u>Slopes</u>.

a. Slopes are those ground surfaces which form an angle with the plane of the horizon. Slopes can be considered as one of the major resistance factors to vehicular movement. Slopes include both natural and artificial inclines and declines and are categorized herein as hill and mountain slopes and those occurring on river banks and ditch type obstacles.

(1) The gradient or angle of slope creates the greatest deterrent to overcoming the obstacle; however, such things as the frictional quality of the surface under both wet and dry conditions has a considerable bearing on the ability of a vehicle to negotiate the

incline or decline. For example, it is quite obvious that a loaded 5-ton truck ascending a 60% slope on a dry concrete road would have much better chances of achieving the summit than if it were attempting to go up a wet grassy hillside of the same degree of steepness.

(2) Those slopes which vehicles encounter while traversing streams, ditches, washes, gullies and ravines often are so steep that the front, rear, or belly of the vehicle "hangs up" on the banks.

(3) The consistency and moisture content of soils encountered on slopes would also have considerable effect on a vehicle's ability to negotiate the slope.

b. To overcome the gradient resistance factor, we must consider the necessity for an adequate motive power/gear ratio combination to move the vehicle and its cargo up a desired degree of gradient with the desired amount of speed to satisfy the established requirement. The criteria established for adequate hill climbing ability of those military vehicles designed to operate off-road at times in future operations is considered to be the ability to negotiate a 60-65% slope, carrying the rated load and using the lowest gear.

7. Ditches, etc.

a. Ditches, washes, gullies, ravines and banks of streams comprise another category of resistance factors. The main characteristic of these obstacles is that they generally consist of a steep declivity or acclivity on one or both sides. This type obstacle, which is found in profusion in most types of temperate zone terrain, is a major deterrent to off-road vehicular movement.

(1) In attempting to climb an earth bank where the angle is greater than 45° and where the height is more than about five feet, neither tracked nor wheeled vehicle will meet with much success. Likewise, if the width of a ditch of that depth was only slightly greater than the length of the vehicle, the vehicle's chances of self-extraction are slim.

(2) Banks of ditches and streams in average soils can be readily broken down by bulldozers. A full-tracked vehicle of almost any type can "work" the tracks on the edge of a bank and break off the soil so that the spoil falls into the ditch, thereby allowing a more gradual descent into it. Wheeled vehicles are not as effective as tracked ones in this maneuver.

b. To surmount the difficulties encountered in attempting to traverse this type obstacle, the angles of approach and departure (the angle formed by a line drawn tangent to the most forward - or rearward- projection of the chassis and the front - or rear - tire in relation to the horizontal surface) should be approximately 90°. In order to improve the "bellying" (angle of break) characteristics of wheeled

vehicles when descending or ascending ditch banks, the space on the underside of the chassis located between the rear of the front wheels and the front of the first set of rear wheels should not be encumbered with underslung gas tanks, spare tires, tool boxes or canvas storage racks, as these items tend to foul on ditch banks and this reduces the ability of the vehicle to cross such obstacles.

8. Snow and Ice

a. This study has confined itself to the temperate zones and has considered that snow and ice are resistance factors that may be encountered at times during the year, but that snow and ice are not present year around. If snow and ice were to be the terrain condition present throughout the year instead of a seasonal condition, specialized vehicles designed specifically to combat this resistance factor would probably be more feasible.

b. The standard military cargo vehicles of the present-day fleet meet with varying success in moving through snow and over ice. The integral truck with all axle drive is more versatile when operating in snow and ice than is a semitrailer type.

c. (1) Dry snow and ice conditions offer much better traction than does wet snow and ice. In dry snow the depth and the degree of slope involved are the major deterrents to movement.

(2) Several inches of wet snow, even on paved roads, create a tremendous deterrent. Any slopes involved under these conditions multiply the resistance, and unless additional tractive devices are installed on the vehicle or the surface is sanded, mobility decreases rapidly with the degree of slope.

d. Dry snow can be compacted fairly easily and makes a fairly stable roadbed, as long as snow does not become wet and the gradient is small. With increased compaction, snow tends to become ice, which again greatly deters movement.

e. Ice normally hinders ordinary vehicular movements, however, ice can be a definite aid to movement in many swampy or marshy areas and on many bodies of water, when the proper thickness of ice exists.

f. (1) Inhabitants of the northern regions of the temperate zones, where snow and ice exist in varying amounts for several months of the year, discount the conditions as being major problems. Snow plows clear off the thick snow, sanders increase the surface friction factor where required, and within a day or two after the heavy snow storms, traffic is moving at the usual over-the-road pace.

(2) In an area such as Eastern Virginia or Maryland, where snowfalls occur but rarely, highway departments are not adequately equipped

to combat the condition, and traffic rapidly grinds to a halt in a storm that would be considered as a mere traffic nuisance to a native of Northern Wisconsin or Maine.

g. Snow and ice must be considered as one of the natural conditions to be expected at certain times of the year in many temperate zone areas. Prevention of the condition does not appear possible; therefore we must devise means of minimizing its adverse effects. Snow removal ploughs and sand spreaders must be available for use when snow and icy road conditions are expected. Additional tractive devices for vehicles help considerably in negotiating ice and snow.

Annex B to Staff Study (Vehicle Cross-Country Mobility)

VEHICLE PERFORMANCE CHARACTERISTICS

1. The following definitions and explanations of terms are extracted from TM 9-8000 (January 1956).

a. Angle of approach - the angle of the maximum grade that a vehicle can approach on the horizontal and start to climb with no part, except tires or tracks, coming into contact with the grade.

b. Angle of departure - the angle of the maximum grade from which a vehicle can depart on the horizontal without any part, except tires or tracks, coming in contact with the grade.

c. Cruising range - the total mileage a vehicle can operate on the contents of its fuel tanks.

d. Ground pressure (flotation) - the amount of load carried by each square inch of projected contact area of the vehicle's tires or tracks.

e. Fordability - expressed in inches of water that a vehicle can go through under its own power.

f. Gradeability - the maximum grade that a fully loaded and equipped vehicle can climb at constant speed on a smooth concrete course when operating a specified gear range.

g. Ground clearance - the distance between level ground and the lowest point on the undercarriage of the vehicle.

h. Tractive effort - the thrust of forces of the tire against the ground (per pound of vehicle weight) that is available at the tire surface for moving the vehicle.

i. Turning radius - the radius of the arc described by the center of the track made by the outside front wheel of a vehicle when making its shortest complete turn.

j. Vehicle net weight - the weight of a fully equipped vehicle in operating condition with fuel, lubricants, and water, but without crew or payload unless otherwise specified.

k. Vehicle payload - the weight of cargo or passengers including crew which may be safely imposed on a vehicle.

1. Vehicle gross weight - weight of vehicle fully equipped and serviced for operation, including crew, plus maximum allowable payload of cargo and passengers.

2. The following terms and definitions are not included in TM 9-8000 (January 1956), but are considered to be necessary performance characteristics for cross-country mobility.

a. Side slope lateral stability - the ability of a fully loaded vehicle to execute a 360° turn on any slope that it is capable of climbing (expressed in % slope).

b. *Angle of break (vertical obstacle clearance) - the ability of a vehicle to neogtiate a given vertical change in running surface without bellying (expressed in inches).

3. Cone index - the index of SHEAR STRENGTH of soft soils, measured by the cone penetrometer and expressed in INDICES.

*Applies to wheeled vehicles

Annex C to Staff Study (Vehicle Cross-Country Mobility)

SUMMARY OF COMMENTS

1. U. S. Army Transportation Research and Engineering Command - Complete concurrence.

2. Office of the Chief of Transportation - Approval, subject to incorporation of minor suggestions; these minor suggestions have been embodied in the study.

3. The Ordnance Board, Aberdeen Proving Ground, Maryland - Concurrence in the degree of cross-country mobility required for the motor transport fleet in the long-range period and the method of measurement; however, they do raise doubt as to the practicality of several of the performance characteristics established in the study which are discussed as follows:

a. Ordnance comment: "Vehicle performance characteristics as outlined in paragraph 5c of this study are not considered realistic for application to all motor transport vehicles. While these high performance characteristics may become mandatory for close support within division and corps forward areas, these performance characteristics are not entirely supportable for vehicles engaged in line-haul operations."

(Answer: The study emphasizes the need for "high performance" throughout the theater for cross-country movement and the reasons are given. It does not stipulate that these cross-country performance characteristics would apply to all line-haul vehicles.)

b. Ordnance comment: "This study does not give any consideration to the costs involved in providing a vehicle fleet having the desired optimum performance characteristics. For example, the requirement for navigability, to include a water speed of 7 mph and water steering, may demand a complex and costly vehicle of the DUKW type. Such vehicles have a specialized role, and it is uneconomical to build such characteristics into every vehicle. In addition to the cost, these characteristics would further add to the already complex maintenance and supply problem."

(Answer: This study did not consider costs. The ultimate cross-country vehicle may cost less than existing conventional transport types.)

c. Ordnance comment: "This study concludes that combat support vehicles must have cross-country mobility comparable to the most mobile tactical vehicles. It may be necessary to develop full tracked vehicles to attain this capability in support vehicles. The number of tracked vehicles then required would create a very substantial maintenance and supply problem."

(Answer: The study does not propose any specific tractional system.)

d. Ordnance comment: "This study makes no reference to the GOERS Wheeled Vehicle Study, and yet GOERS have potential mobility at least approaching that of tracked vehicles."

(Answer: It is an Ordnance problem to determine the tractional mode to meet the study requirement, which they say is "ADEQUATE"; the GOER concept vehicle is acceptable if it meets the performance requirements of this study.)

e. Ordnance comment: "The requirement to perform a 360° turn on a 60% slope appears unnecessarialy stringent. Slopes occurring in natural terrain almost never exceed 30%. Lateral stability of the order recommended in this study may force compromise with other desired features. For example, the desired 18 inch ground clearance may have to be sacrificed in order to obtain the low center of gravity required for the degree of lateral stability discussed above."

(Answer: If we have a climb-ability of 60% and cannot fully use it in cross-country operations, its value is lessened. TC should continue to require the present 60% vehicle gradeability performance characteristic with the goal of achieving comparable lateral stability of 60%; however, TC should accept a lesser lateral stability if Research and Development proves the optimum of 60% is not feasible with an 18" ground clearance.)

f. Ordnance comment: "The study includes a statement of requirement for suitable testing facilities for vehicles developed in the future. A careful review of the facilities required indicates that all are in existence at Aberdeen Proving Ground. In addition to the facilities listed in the study, the Ordnance Corps has developed more extensive test courses at Aberdeen Proving Ground, at the Ordnance Test Agency, Yuma, Arizona, and at the Arctic Test Detachment, Fort Churchill, Manitoba, Canada."

(Answer: Concur. Physical observation of the existing vehicle testing facilities at the Aberdeen Proving Ground would indicate the above statement to be correct.)

g. Ordnance comment: "It would be to the best interests of the Department of the Army for the Transportation Corps to have its new vehicles tested at the facilities available within the Ordnance Corps. During performance of the testing by Ordnance Corps personnel, the presence of observers from the requesting agency is encouraged."

(Answer. Concur.)

COMBAT DEVELOPMENT AND THE ENVIRONMENT

Johannes Vrugtman

U. S. ARMY TRANSPORTATION COMBAT DEVELOPMENT GROUP

Fort Eustis, Virginia

B

COMBAT DEVELOPMENT AND THE ENVIRONMENT

At first glance, the development of concepts for transportation support of Army forces under conditions of future warfare, which is the mission of the Transportation Combat Development Group (CDG), would seem to have little relationship to environmental research as practiced in the Army. True, concepts of future operations are vitally affected by the environment of potential theaters of war, but such environmental data as may be required by the CD researcher are provided by the environmental specialist; therefore, no environmental research as such is conducted in the Combat Development systems.

AR 320-5, the Dictionary of United States Army Terms, defines environmental research in part as "The collation of statistical, meteorological, climatic and geographical data . . . , the interpretation of these data . . . for application . . . to logistic problems of equipment, personnel and operational functions." Environmental research in the Army is concerned, therefore, with the physical environment and with the question of how men and materials behave therein. In civilian usage, the word "environment" does not have quite so restricted a meaning. Depending on the discipline concerned, one speaks of social environment, biological environment, psychological environment, and the like. Since every external influence on an organism constitutes, in fact, a part of its environment, it may be permissible to add the term "weapons environment" to our lexicon. The weapons environment encountered in future wars will be one of the most important considerations affecting Army organization, tactics, and logistics, and it may well be considered the proper object of Combat Development studies. The intent here is to use the term in somewhat the same sense as the combat forces use "battlefield conditions" but to apply it to the field of logistics and, more particularly, to transportation. The purpose of this short paper is to provide some insight into the special form of environmental research in which the Transportation Combat Development Group is engaged.

To enlarge upon our definition, the weapons environment is man-made and superimposed on the physical environment. It is also transitory and varies both with the physical characteristics of the theater and with the type of war. The nature of future war and of its weapons environment must be predicted reliably if valid decisions are to be made as to what types of organizations and tactics should be employed and as to what direction Research and Development (R&D) programs should take. Accurate prediction of the nature of future battlefield conditions is of fundamental importance to the tactical planner, while the nature of the weapons environment in the communications zone of a theater of operations is of vital concern to the logistical planner.

Since a weapons environment occurs only under actual combat conditions, the usual techniques of environmental research are not applicable to the weapons environment. The conditions of actual warfare generally are not conducive to calm observation, data collection, and analysis. Even if such techniques were possible, the results thereof could not be made available as rapidly as necessary to affect decisions in the field. Since the experimental approach is also impractical, the example of the Spanish Civil War notwithstanding, it is little wonder that the question of what conditions of future warfare the Army should prepare for, occupies many minds. The CD researcher at the working level starts his studies by first reviewing official guidance on this subject. Official guidance as to the nature of future war is necessarily broad and can be summarized as follows:

a. There are two types of war, general and limited.

b. General war is a conflict in which the United States is directly pitted against the Communist bloc, and one in which atomic weapons will be employed f om the start.

c. A limited war is a conflict in which the objectives, weapons used, and/or area of operations are restricted.

Planning for general war as defined is, if not impracticable, beyond the scope of CD activities. CD studies are, therefore, aimed at wars, with constraints. Unfortunately, the definition of limited war covers such a broad spectrum of possible conflicts that the situation is not greatly clarified by this restriction. It leaves many questions, to include some which may be unanswerable. For example, how limited is limited war? What about the possibility that small nuclear weapons will be employed, notwithstanding the obvious danger of escalation? As stated, these questions may be impossible to answer; but it is clear that if enemy intent proves irrational, the world will be confronted with an all-out war. Thus, enemy intent must be assumed to be rational and, in that case, evaluation of the nature of future wars may be based on anticipated enemy capabilities in the field of limited war weapons.

The CD researcher examines information on enemy capabilities derived from intelligence reports, analyzes technical reports on the Free World's weapons systems and reviews technological trends and prospects. For planning purposes, he may grant the USSR parity in the field of weapons technology and perhaps an advantage in the R&D/production time cycle.

Before going further, it may be well to attempt a definition of a limited war weapon. A reasonable postulate here would seem to be that a weapon is suitable for limited war when its employment does not directly threaten the independent political existence of any of the major powers involved. It is recognized that such a definition does not rule out the use of nuclear weapons and the destruction of a smaller nation or of the territory in which the limited war takes place, but placing of lower values on limited war weapons would probably be unrealistic. The development of small nuclear weapons has gone too farffor that.

To evaluate the effect of new weapons, organizations, and tactics, computer-assisted war gaming techniques are employed. War gaming as the name implies, is normally confined to the study of tactical situations. However, in recent years these techniques have been applied to logistics problems. In the field of military transportation, for instance, efforts have been made to use war gaming to predict the effects of atomic attack on ports and rail and highway nets. Thus far, however, very little work has been done on the question of how an entire theater transportation system might behave in a limited war weapons environment. An attempt is currently being made by the U. S. Army Transportation Combat Development Group, assisted by the Mathematical Sciences Division of the U. S. Army Transportation Research Command, to evaluate via war gaming the reaction of the water terminals segment of a theater transportation system to a varying weapons environment likely to prevail in limited wars after 1965.

Stated simply, the original prlblem was to determine what water terminal equipment, organizations, and operating methods will most effectively support combat forces in future oversea theaters. It developed early in the study, however, that conventional analytical methods would be inadequate to provide the answer. The enormous advances being made in missile technology, especially in the field of tactical missiles, made it clear that water terminal operations might have to be conducted under a very wide range of conditions. The future weapons environment, it was found, might vary from one in which the only danger is sporadic conventional air attack and local sabotage to one in which the enemy makes a determined effort, with every means at his command, to prevent ship discharge. The net effects of such attacks would depend, of course, on the effectiveness of the defense and on the vulnerability of the system used to transfer cargo from ship to shore.

Although large missiles carrying area destruction warheads were ruled out as inappropriate weapons for limited war, tactical missiles with conventional warheads are peculiarly suited to limited warfare conditions.

Moreover, tactical guided and homing missiles are becoming so reliable, accurate, and flexible that they loom as a major threat to water terminals and ships in coastal waters. In addition, these weapons have the virtue of being "exportable" to communist satellites and their allies as they are unlikely to expand the scope of a war. Moreover, should the enemy decide to risk nuclear war, almost any one of these missiles can be armed with nuclear warheads.

The accuracies being achieved with liquid- and solid-fuel surface-to-surface and air-to-surface missiles, at ranges which cover the whole of most potential limited war theaters, are already greater than those of manned bombers in World War II. In the long-range time frame, it is possible to predict that fixed coordinate targets such as bridges, railyards, and built-up depot and port facilities will be subjected to highly accurate fire by inertially and radar-guided missiles; radar installations will be attacked by missiles which home in on their emission; and transport equipment such as ships, aircraft, locomotives, and some of the larger land vehicles will become excellent targets for heat-seeking passive homing missiles.

There has never been a new weapon for which a counter could not be found, and great advances are being made in aircraft and missile defense. While the offensive tactical missile is in the ascendency, however, it should be borne in mind that a new weapon can be decisive in a single battle or campaign, as history has shown time and again. In the nuclear age, a limited war in which one side has a temporary advantage may place the opponent before the choice of accepting defeat or expanding the scope of the conflict.

In the computer-assisted simulation of water terminal operations, a specific potential limited war area was selected, and its climate, geography, hydrography, transportation facilities, ports, landing beaches, and suitable ship anchorages were studied for use as computer inputs. The coastline was divided into a number of sectors based on available ship berths and anchorages. On the assumption that even in a limited war situation it would be wise to disperse operations to avoid excessive losses in case of nuclear attack, the ship berths and anchorages were laid out at intervals of 1/2, 1, and 5 miles. The ship anchorages were so located that none would be either more than 5 miles from the shore or in water of over 35 fathoms in depth. Ship discharge berths were divided into alongside berths in the case of ports, stream berths in protected anchorages, offshore berths in open waters, and beach berths. Five basic ship types were selected: a dry cargo ship, which incorporates the characteristics of the average vessel in the U. S. Merchant Marine fleet by 1968; a roll-on/roll-off type ship along the lines of the USNS COMET; a heavy lift ship of the Bel or

Empire class; an LST; and a conceptional beaching type ship. Only dry cargo was considered in the study. This was broken down into three major categories: vehicles and mobile equipment, general cargo, and non-mobile heavy and outsize lifts. The ships were used in various combinations and were discharged by different methods; e.g., to piers or wharves in port, to lighters in the stream and offshore, and, as in the case of LSTs, directly to the beach. Different discharge rates were established for each ship, depending on the type of cargo carried and the type of discharge berth assigned. The discharge rates were varied so as to allow for normal and climatically induced fluctuations. As a passive defense measure, the ships were moved periodically; and in one case, they were moved constantly, but at a sufficiently slow rate to permit lighters to come alongside. The system was given the task of delivering a certain range of tonnages per day with the provision that if the minimum could not be reached over a 30-day period, the operation would be considered a failure.

The weapons environment in which these operations are assumed to take place is created by a "red" offensive system and a "blue" defensive system of varying capabilities. Although this approach is parametric, the values used are based on known and predicted capabilities of applicable weapons systems evaluated against each other qualitatively as well as quantitatively. The "red" and "blue" systems are set up so as to favor each side in turn. This is done to obtain a "clean" answer as to the effect on terminal operations of each weapon system, both offensive and defensive, and to simulate as closely as possible actual combat conditions which tend to seek a state of balance.

The study has reached the stage where the system has been programmed and placed in a digital computer. The computer will play the game according to a set of pre-arranged restrictions. Some of the steps in the computer process are shown in Figures 1 through 3. The human element enters the simulation in the form of the "blue" commander, who decides the number and types of ships to be sent in, when they will arrive, and where they will be discharged. The various events not decided by the "blue" commander occur in accordance with random selection by the computer. Random variations introduced by the computer include the effect of weather on the discharge rate. This is based on a statistical distribution of weather conditions in the area. Since the number of cases or sets of conditions to be analyzed by the machine is quite large (some 20,000), sampling techniques such as factorial analysis and regression equations are being employed to reduce machine time. The computer will print out daily status reports, showing the number of ships being discharged and their percent completion, the total tonnage delivered during the period, the number of ships damaged and lost, the number of fixed terminal

facilities attacked, the quantity of cargo lost due to enemy action or recoverable from damaged ships, the number of "red" surveillance craft (drones and manned aircraft) lost, and the number of "red" weapons fired. After the computer program has run its course, the gross cost to either side of each of the strategies employed will be calculated. In this manner, it is hoped that an optimal operational strategy may be selected for the delivery by surface transport of supply and equipment to the theater concerned for each level of investment. If applied to a number of potential war areas and to various potential weapons environments, this form of analysis should yield a decision matrix from which it will be possible to determine what operating techniques, equipment, and defense systems will offer the best chances of success for the money invested under all circumstances and in all theaters. It should be added parenthetically that there is no guarantee that only one set of equipment and operating methods will prove to be optimal for each type of theater and weapons environment or that the best method will necessarily be the least expensive.

A study of this type cannot answer the question "What will the enemy do?"; but it will show that the net result will be of operating under a spectrum of probable conditions- - in this case, how much cargo can be delivered and what it will cost. Another important result of the study will be that it will provide alternative courses of action both for the logistic planner and for the responsible commander in the field. The planner should be able to tell, for instance, what a given investment in air defense or transportation and terminal equipment will buy in terms of cargo delivery capabilities. The terminal commander will know what operating methods to use when his facilities and operations are attacked in a certain manner.

In summary, short of achieving clairvoyance, no reliable method exists for predicting the nature of the future weapons environment or its effect on the military transportation system. By identifying the weapons environment parameters and by varying their values within selected ranges, it is possible, however, to determine what might happen and how any segment of a theater transportation system is likely to perform. From this, it will be possible to determine what equipment and operation techniques provide the best results under any given set of circumstances. This, in turn, should provide fairly clear guidelines for long-range R&D and operational planning.

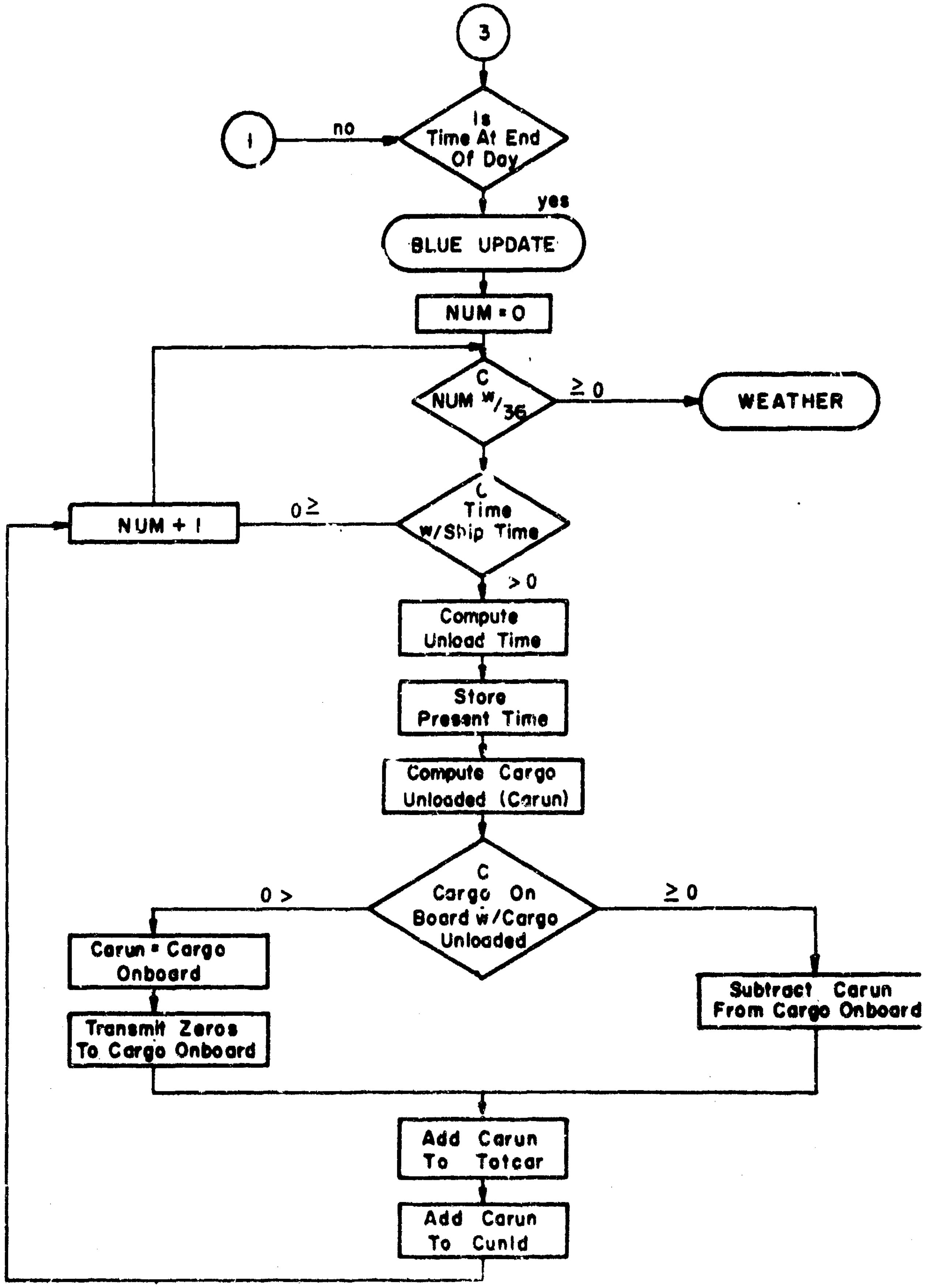


Figure 1. Blue Update. (Abbreviations and codes used in Figures 1-3 are explained on page B-10.)

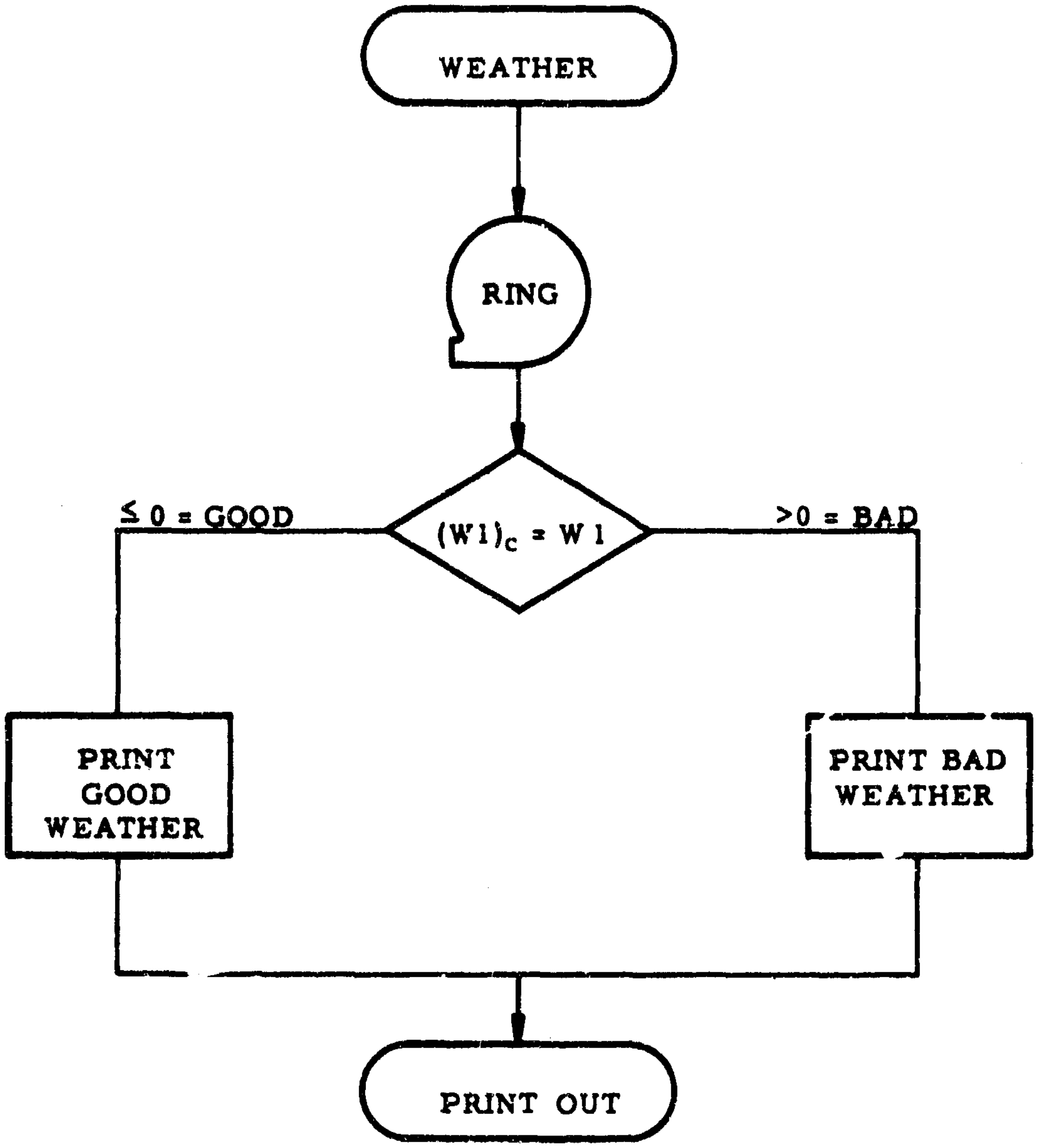


Figure 2. Weather.

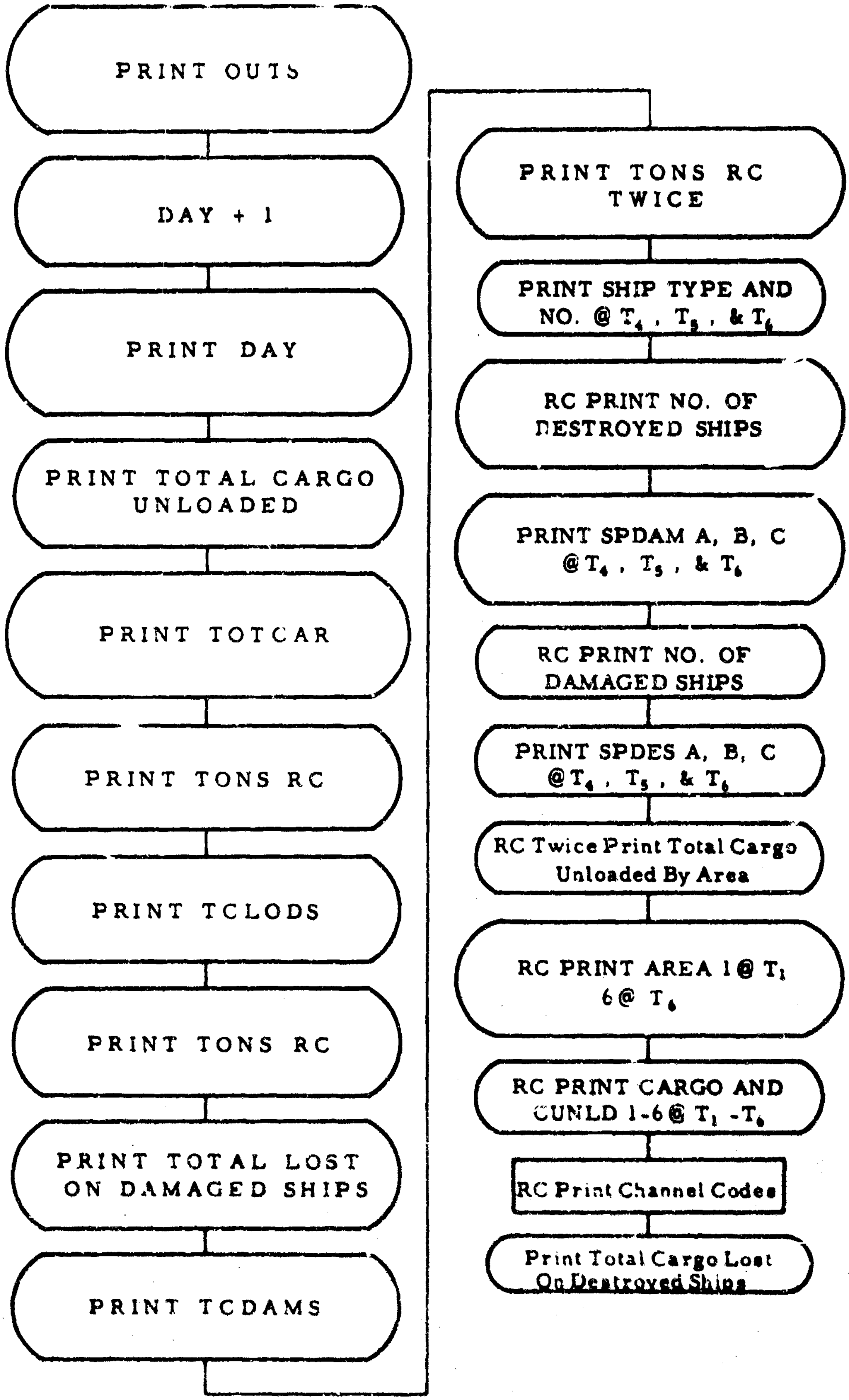


Figure 3. Print Outs Blue.

DEFINITIONS OF MNEMONICS

<u>Carun</u> - a dummy for storing the amount of cargo unloaded during last up-date period to be compared to amount of cargo aboard ship. The smaller of the two quantities is then added to the total cargo unloaded counter.

<u>Cunld</u> - a table for storing the amount of cargo unloaded by area.

<u>NUM</u> - a counter used for address modification of the channel codes.

<u>RC</u> - return carriage.

<u>Spdam</u> - total number of ships damaged by ship type.

<u>Spdes</u> - total number of ships destroyed by ship type.

<u>Tcdams</u> - total cargo damaged by area.

<u>Tclods</u> - total cargo unloaded by area.

<u>Totcar</u> - total cargo unloaded.

MOBILITY AND WARFARE IN 1965-1970

E. C. Hurford

U. S. ARMY TRANSPORTATION COMBAT DEVELOPMENT GROUP

Fort Eustis, Virginia

C

MOBILITY AND WARFARE IN 1965-1970

In an address delivered at Fort Eustis in March 1961, Lt. General Trudeau, Chief of Army Research and Development, said that the combat equation contains three important ingredients: firepower, communications, and mobility. He described how the Army has improved its conventional artillery and obtained a tremendous increase in impact power by perfecting missiles such as the SERGEANT, the PERSHING, and the LaCROSSE. He also said that he believed the satellite circuit was the prescription offering a cure to illnesses existing in the communications field. However, he emphasized that mobility is the field in which the Army has the greatest need for progress today.

We in the Transportation Corps (TC) take pride in being called "The Core of Mobility". It is obvious, therefore, that we are vitally concerned with all environmental elements affecting mobility. Within our corps, the Transportation Combat Development Group has the mission of studying and finding solutions to the many problems which will complicate the job of hauling men, materiel, and supplies to the combat forces of the future in all environments.

The urgency of our job was described in the Army Information Digest by General Eddleman, the Vice Chief of Staff, when he wrote: "Notwithstanding the fact that the world seems to be obsessed with the novelty of missiles and outer space, a major advantage will accrue to that nation which gains a decisive lead in developing new logistical support capabilities." He wrote further: "Mobility has always been a military asset, but never more than today when it has been called to the center of the stage, not only on its own merits, but also as an antidote to the dispersion which has been forced on us by nuclear weapons." The U. S Army thus must be able in all environments to run-hit-run. This is imperative according to General Eddleman's statement.

The purpose of this paper is to provide a survey of the major problem areas facing the Transportation Corps in providing the Army of the future with mobility in all environments. It may, perhaps indirectly, show how dependent the TC of the future will be on the recommendations of people engaged in environmental research.

Army mobility, in the broadest sense, can be considered in three major categories: strategic, tactical, and logistical.

The first major category strategic mobility, is primarily a responsibility of the Air Force and the Navy. In recent months, the subject of the air transportation resources available from the Air Force to transport our strategic Army forces has received considerable attention from the President, the Congress, and the Department of Defense. We are pleased to note that progress is being made in this area, since the Army's power is worthless unless it can be projected rapidly to any area in the world when and where it may be needed

The Army must depend upon the Navy for its ocean transport requirements. The establishment of the Military Sea Transportation Service as the single manager for ocean transport was undoubtedly based on sound managerial principles. However, I believe it will be apparent that the assignment of these strategic transport roles to the other services does not solve all of the Army problems in these areas. In fact, this division of responsibility within the Department of Defense for the provision of transportation services has complicated the solution of some of our mobility problems. It is really impossible to draw a distinct line between strategic mobility and the Army's requirements for tactical and logistical mobility.

While the Transportation Corps is vitally interested in the ability of the Navy and the Air Force to provide strategic mobility for Army forces, it is more immediately concerned with the provision of tactical and logistical mobility within the Army. Consequently, this paper will be concentrated in these two areas.

Our responsibilities in providing tactical mobility for combat forces have grown significantly during the past few years. The transportation battalions in the infantry divisions, with their armored personnel carriers and light trucks, and the Army Transportation transport helicopter battalions are TC units used by combat commanders in tactical operations.

Whether our responsibilities in the combat zone will grow in the future hinges primarily on the question of the desirability of pooling transportation resources there. The combat commander would certainly like to have his combat elements possess sufficient organic transportation to move them rapidly whenever and wherever the combat situation demands. But can we afford the materiel and supplies necessary to give the combat commander this 100-percent organic mobility?

If we cannot reach this goal and must settle for the lesser goal of improved mobility through the pooling of transportation means, then the role of the TC will probably remain essentially the same in this area. We believe that the operations of pooled transportation can best be accomplished by officers and men trained in transportation.

It is in the third category, logistical mobility, that we find the greatest challenge facing the Transportation Corps of the future. I would like to refer again to General Eddleman's article for his views on the Army's requirement for logistical mobility. He wrote: "The problem sometimes fails to attract the attention it deserves because it is so large, hydra-headed and colorless. Some progress is being made; however, in comparison with the distances yet to be covered, that progress is slow."

To provide mobility for the Army's logistical system, the Transportation Corps must be able to haul the men, materiel, and supplies in the quantities needed and at the times desired, to the combat forces of the future. This job will be greatly complicated by the environments in which we will be forced to operate.

We recognize that we must prepare for a spectrum of war environments varying from the cold war, the sub-limited wars such as have existed in Laos and the Congo, limited war as we knew it in Korea, and a condition of total war in which all the resources of both sides are fully employed and national survival is at stake. Each band in this spectrum differs from the others in one or more respects.

However, the demands placed on the Transportation Corps in general war and limited war are almost equally perplexing. In general war, we assume that the large port complexes and the fixed lines of communications either will be destroyed or, representing such lucrative targets for the enemy's mass destruction weapons, will be denied us.

In many respects the problems we face in limited war are comparable. The areas where such a conflict is most likely to erupt are characterized by natural environments which place great demands on the transportation systems. These areas lack conventional lines of communications. We won't have the time to build transportation facilities, since speed of reaction is of paramount importance in a limited war. This makes the situation very similar to a general war where the facilities exist but are denied. Most of the potential limited war areas not only lack roads, railroads, and airfields, but they are characterized by natural obstacles to free movement, including severe climatic conditions which produce arctic or desert wastelands or humid jungles and swamps. Our present equipment and systems

are too sophisticated to operate in primitive areas where roads and airfields are in poor condition or nonexistent. Yet, our equipment and systems are not sufficiently sophisticated to permit us to operate completely independent of these environmental limitations to mobility. Our basic mobility problems in primitive areas remain unsolved.

The communist bloc must be acutely aware of our dilemma and is certainly capable of undertaking provocation in these areas least suited to our capabilities. Laos and the Congo are two outstanding illustrations.

Passing from the general to the specific, I would now like to review three major problems facing the Transportation Corps in providing mobility for the Army's logistical system operating in all environments. These are:

a. Providing transportation at the entrance to the overseas theater,

b. Moving supplies from the point of theater entry to the combat forces.

c. Managing the transportation resources within the theater.

The first problem concerns, fundamentally, congestion at the overseas shoreline. While we hope that the Air Force will be able to carry STRAC forces anywhere in the world in emergencies, we believe that sealift will carry the bulk of our troops and supplies to an overseas theater at least through 1970.

The Army Combat Development system has not been alone in its concern over the problem of congestion at the shoreline. In 1959, the Maritime Research Advisory Committee of the National Academy of Sciences studied the role of the U. S. Merchant Marine in national security. One of the conclusions reached by that body as published in the Project WALRUS report stated that "US-controlled merchant shipping is qualitatively deficient for optimum support of civilian and military requirements in a limited war owing to deficiencies in speed, age, rates of, and capacities of unloading systems, and lack of 'over-the-beach' capability."

A number of studies in the combat development field have also pointed out the inadequacy of conventional shipping in supporting Army operations in limited and general wars, especially in those world areas where the natural environments present severe challenges.

What, then, do we need to reduce congestion at the shoreline?

As long as surface shipping is used, there are three basic ways in which shipborne cargo can be transferred to the shore.

a. By lighterage.

b. By the use of air vehicles of the vertical-lift type.

c. By bringing ships directly to the shore.

In recent years, our research and development effort has improved the family of amphibians which we shall have in our inventories in the next few years. I am sure that you are familiar with the BARC and the LARCs. We know that these vehicles represent significant improvements over our World War II amphibians, but they are subject to the same obstacles to free movement on land as are other wheeled vehicles.

In the second transfer method suggested may lie the long-range answer to our problems. We need a family of vehicles which will not be hampered by the various limitations to mobility imposed by the natural environments. Surf, beach gradients, and terrain conditions in the immediate area of the beach often severely limit over-the-shore discharge capabilities.

The desired vehicles would have to possess the characteristics either of VTOL aircraft (helicopters or flying cranes) or of air-cushion vehicles such as the ground environment machines (GEMs). I shall have more to say about these vehicles during my discussion of the problems we face along the line of communications.

The third possible method for reducing the congestion at the shoreline in certain natural environments concerns ships which could bring our men and materials directly to the shore. Beaching ships, such as the LST, are not new and have always had supporters among logisticians. So far, however, no great strides have been made in increasing their speed and their ability to deliver other than mobile cargo to the shore with any real efficiency. We need beaching ships with integral cargo handling equipment, a long bow ramp, and either a built-in conveyor system or vehicle loading docks. A vessel so equipped would enable us to reach the ideal of complete discharge in eight hours or less. We would be able to avoid the traffic problem which would result if we attempted to discharge a number of conventional cargo ships offshore, and our requirements for lighterage would be greatly reduced.

Beaching ships do, however, have disadvantages. Because of their built-in shallow draft capability, they are restricted in size and in speed. They may, therefore, be uneconomical for the long haul. This means that their most effective logistical use may well be between advanced bases and theaters of operations in conjunction with pre-positioned stocks of supplies and equipment.

In a report made at the end of Project WALRUS in 1959, the National Research Council of the National Academy of Sciences concluded that: "There is a military need under limited war conditions for small (3,000 to 5,000 ton capacity) high speed amphibious support ships which are capable of discharging rapidly in small harbors or onto beaches." This report also concluded that such vessels were not envisioned as serving any commercial purposes and would therefore necessarily be a part of the U. S. Navy's mobilization fleet.

It is obvious that the solutions to the Army's problems in this area are largely within the Navy's zone of responsibility. But what priority can the Navy afford for the design, construction, and procurement of such vessels? This is obviously a case in which the solution to logistical mobility problems is found in the means used to provide strategic mobility for the Army. It is not possible to draw a distinct line between the two.

The second problem which I listed as facing the Transportation Corps concerns the movement of supplies from the point of theater entry to the combat forces.

In a nuclear war theater or perhaps, of more immediate importance, in primitive areas with challenging natural environments where limited wars are likely, the lines of communications (LOCs) will present problems having unprecedented complications. The LOCs are the lifelines of the combat forces. In past conflicts, these arteries fed forces operating on relatively stable fronts.

These arteries must now be far more flexible, as they must possess the ability to deliver supplies to a highly mobile consumer. This mobility enables combat forces to present only fleeting targets to the enemy, but in doing so, it makes our job of delivering supplies far more difficult.

There are essentially two approaches to this problem. The first would be to reduce drastically the load of supplies necessary to support the combat forces. The second would be to free the transport means from the obstacles represented by the natural environment and to reduce its vulnerability to enemy fire.

We in Combat Developments are afraid that the first approach is largely a matter of wishful thinking. Much thought has been given in recent years to ways and means of reducing the supply requirements, but the logistic load of the U. S. Army appears to be increasing in spite of efforts and predictions to the contrary.

It is obvious that if we are to make real progress in this area, science must develop power plants which need significantly less fuel per ton/mile. Continued research in nuclear applications and thermoelectric and chemical conversion processes may give us answers in this area.

In addition to fuel-consumption improvements, vehicles must be made lighter in weight and simpler to maintain than those presently in our inventories. All maintenance activities must disappear from the combat zone. Vehicles must be made virtually maintenance-free. Self-lubrication, pluckout and plug-in components, and austere, rugged construction are musts. Class I supplies (rations) must be lightened; and in Class V (ammunition), quality must replace quantity. As we see it, the Army is still a long way from achieving these goals.

The second solution suggested for the LOC problems centers around the development of true cross-country mobility, true point-to-point lines of communications. In this area we again seem to have two possible alternatives. Either we can strive to improve our wheeled mobility as we are doing in the GOER program and in the overland train development, thereby merely modifying the historic concept of fixed lines of communication, or we can strive for a major technological breakthrough which will free us from the ground.

Considering the second alternative, the helicopter and the flying crane free us from the ground. The helicopter is no longer an exotic aircraft; it has a very important role in the Army as a cargo and personnel carrier. These aircraft and improved aircraft with vertical and short take-off and landing capabilities must be obtained in significant numbers for the Army of the immediate future.

Why, then, did I state that, as a second alternative, "We can strive for a major technological breakthrough which will free us from the ground"? Helicopters are expensive and relatively inefficient, and they require the use of highly skilled, premium-paid operators and maintenance personnel. The allocation of economic and personnel resources during war may not permit the extensive use of craft of this nature. We must have a craft which will free us from the ground, but which will be simple to produce, simple to operate, and simple to maintain. It must be economical

to build and to operate. And it must produce economy by its capability and its capacity In short, it must be economically comparable to a truck and not to an aircraft.

The Ground Environment Machine (GEM) has a number of supporters who say it will fill the role and have the characteristics which I have described. The Combat Development Group has submitted a qualitative materiel requirement for a ground environment machine, and we hope that considerable emphasis will be given to the development of this item.

The third major problem is closely associated with the first two. It concerns the management of our transportation resources in the theater. We call this process "transportation movements". It is accomplished, fundamentally, by collecting the transportation requirements from various shippers, by determining the total transport capability, and by balancing the requirements and capabilities in accordance with established priorities.

Our future movements organization must be capable of controlling and, when necessary, rerouting fast-moving shipments by all modes in order to make timely and accurate deliveries. The transportation movements system that exists today is not capable of doing this, simply because it does not have the equipment and techniques to collect data, process it, and issue instructions fast enough.

In addition to the requirement for improved equipment, we believe that the transportation movements system will see changes in its operational doctrine in future wars. Since the problem in attaining true centralized management of transportation resources under conditions of future warfare seems insurmountable, we may be forced to decentralize our operations to a certain extent. More authority for the management of transportation resources may have to be given to personnel in the field throughout the area of operations. They will have to do the best possible job with the tools at hand. This concept of decentralization may have to be the answer, but it must be remembered that the efficiency of management of transportation resources decreases with decentralization.

Something must be done, therefore, to solve these problems of transportation movements. I believe that a solution can be found in improved data processing and communications equipment which will allow us to centralize our movements planning, but permit us to decentralize the implementation of these plans. The assignment of organic high-mobility vehicles and aircraft to movements teams will be necessary to enable them to be as mobile as the tactical and logistical elements which they support.

In summary, let me say that in essence the three separate problems I have discussed are really integral parts of the overall concept of logistic mobility. We would like equipment which will allow us to move anywhere in support of the combat forces, relatively free from restraints imposed by either the enemy or the natural environment. And we would like the managerial tools to provide maximum control and economy of utilization over this equipment. I suppose that that is ultimately what every logistician in the history of warfare has strived for. But I seriously doubt if at any time in history the need has been more pressing.

POLAR ENVIRONMENT, ANTARCTICA

Lieutenant Colonel Merle R Dawson

U S ARMY TRANSPORTATION BOARD

Fort Eustis, Virginia

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POLAR ENVIRONMENT, ANTARCTICA

Several events in recent years have combined to focus a lot of interest on the Antarctic Continent. Men have plunged to their deaths in airplane crashes while others have fallen with their tractors into crevasses and the icy seas. Ships have been crushed in the jaws of closing ice.

On the more cheerful side of the ledger, man has landed an airplane at the geographic South Pole for the first time, several thousand square miles of unexplored territory have been seen and mapped, huge tractor trains have navigated the icecap to points hundreds of miles inland, and airplanes have dropped cargo to build a scientific camp at the South Pole.

Houses fabricated in America, Japan, England, Russia, and half a hundred other nations of the world have been ferried into the Antarctic by ship and by aircraft to be assembled on the ice.

Individually, the stories reflect drama, adventure, castastrophe, heroism, and accomplishment. Taken collectively, as pieces of a jigsaw puzzle, they spell out the problems that have been overcome by Americans and men of many nations who went quietly about their task of building houses on the snow and ice for the scientists who are now studying the many secrets of Antarctica, our seventh continent, with her icy face hidden behind a curtain of fog and snow.

In the International Geophysical Year, 1956-58, scientists from 12 nations made an all-out assault on the most stubborn secrets of our planet in Antarctica. These scientists concentrated their studies upon solar activity, latitude and longitude determination, glaciology, oceanography, meteorology, geomagnetism, aurora and air glow, ionosphere physics, seismology and gravity, cosmic rays, and upper atmospheric rocket exploration, including the use of instrumented satellite vehicles. During these studies, scientists as well as the support personnel found that environment played a very important part in their success.

Environment is the aggregate of all the external conditions and influences affecting the life and development of an organism, i.e., human behavior, material behavior, society, etc. In Antarctica, environment is at its extreme, with temperatures ranging from 45 degrees above zero to 125 degrees below.

The Antarctic is believed to be a breeding place for the world's weather, especially the Southern Hemisphere. The furious storms of the antarctic winter are a major factor in determining the weather in the south latitudes, and their effects even extend across the Equator into the Northern Hemisphere. Scientists and observers at antarctic stations have an invaluable opportunity to study this weather in the making, to follow movements of the atmosphere, and to relate these to weather in other distant regions.

The Antarctic is obviously a primary source of data for the glaciologist; it is the largest single repository of snow and ice on the surface of the earth. Studies of successive layers of antarctic ice can tell us much about the climatic history of the earth and, more important, reveal much about our changing climate and environment here at home.

The absence of the sun during the long winter polar night also has its effects on the ionosphere. Radiation from the sun, specifically ultra-violet and X-radiation, breaks up the atoms and molecules in the upper atmosphere into electrons and positive ions. These electrically charged particles, in effect, make a mirror of the ionosphere so that it reflects radio signals. However, in the long antarctic night, 23 March to 23 September, particularly at the South Pole, the sun's radiation is absent; and this gives rise to the important question of the composition and characteristics of the ionosphere under these unique and interesting conditions. Communication blackout is frequent and has an environmental impact on all operations.

Twelve nations are operating 40-odd scientific bases on the Antarctic Continent, on its sea-riding ice shelves, and on its adjacent islands. American scientists and their large supporting crews are now gathering much data at our four remaining American bases, including the most popular one, at the South Pole. These scientists are not merely waiting for the coming crucial polar summer, but are making the most of the darkness, the long, dark winter night at the other end of the earth, fraught with its own mysteries. They are living in their small, but fully equipped, stations, sealed off from the world. Their only contact with the outside is by HAM radio.

The Antarctic, covering an area of 6,000,000 square miles, is approximately twice the size of the United States. Think of this vast territory, still much of it unexplored, and compare its population--810--with that of our country--180 000,000--living in half the area. Think of your nearest neighbor being some 450 miles away, a few hours by air, but 10 or more days by surface vehicle.

Antarctica is totally deficient in essentials required for living, as everything needed for man's support and survival has to be imported by ship or aircraft. There is virtually no vegetation and relatively little soil, no construction material, and no land animals. Marine mammals such as whales and seals are plentiful, but there are only a few species of birds and fish. Water is available only from melted snow.

Travel to the interior produces a rapid transition from coastal to mountainous conditions. This transition necessitates special equipment for living and working at extreme elevations. Environmental impact on men and machines working under these conditions is tremendous. At 40 degrees below zero, equipment begins to develop varied mechanical breakdowns; we in the Antarctic classify this 40-degree point as a cold barrier. The cold, the climate, and the great heights, combined with the hazardous ice and surface conditions, create some of the most difficult operating problems in the world.

The encircling ice in the surrounding waters is a continual menace to all shipping and landings along the Antarctic's barren and inhospitable shores, which makes the continent inaccessible except at a few places for most of the year. The width of the surrounding ice pack in winter ranges up to 1,500 miles and in the summer to about 200 miles. The climate in summer, although not so severe as in the winter, is still a major contributing factor to dangers present.

The South Pole station rests on a polar plateau of approximately 10,000 feet, some 9,000 feet of snow and ice above sea level. Ice and snow coverage in the vicinity of Byrd Station, the other inland station, averages 10,000 feet: 5,000 feet above and 5,000 feet below sea level. The thickest ice and snow coverage ever recorded is 14,000 feet at a point some 150 miles east of Byrd Station.

Working at and around these stations creates other problems, particularly those of a psychological nature. These problems result from boredom and from long periods of confinement due to the restriction of outdoor activity in the cold winter months. Here human environment has its effect; reliability of man is at its lowest ebb.

Crevasse areas form along the steep coastal areas and along the approaches to the plateau regions. These areas are the principal terrain hazards and obstacles to cross-country movement. The continental glacier is generally flat or rolling, but it is often covered with high, hard sastrugi. Sastrugi are formed as the snow is swept across the ice by high winds and drifted into patterns of shallow designs. The depth of these drifts ranges from

6 inches to 6 feet. Usually the surface is tough, hard, and wind packed; however, in a few areas a very soft powdery snow exists, but these areas are clearly defined by distinctive color patterns.

The main United States base, the Naval Air Facility, McMurdo, has the only airstrip for wheeled aircraft in Antarctica, an ice runway carved out of the sea ice that covers the surrounding waters of McMurdo Sound. Construction of this runway is a yearly chore, as the sound ice breaks free and floats to sea each year.

Two of the four U. S. bases, McMurdo and Hallett, are located near the sea and can be supplied by ship in December and January; but the two interior bases, Byrd and Pole, present a different problem: they have to be supplied by air and/or tractor train. The U. S. Air Force has the responsibility for conducting airdrops at these inland stations, which are usually done by C-124 Globemasters. This resupply is supplemented by Navy C-130B Hercules ski-equipped turboprop aircraft. Resupply of scientific parties in the field is generally conducted with the Navy R4D (C-47) or P2V Neptune ski-equipped planes. Personnel at the inland stations and on scientific field parties are exchanged by use of ski-equipped aircraft.

Since World War II and the Korean war our horizons have continued to expand with extended defense perimeters, which has resulted in a definite need for additional environmental studies. Environmental problems and their solution today consume a significant percentage of the effort of technical activities throughout the military services. The size of the total job cannot be reduced, nor can its importance be overestimated. Consequently, it must be understood that solutions to the technical problems lie not in one test, but in a variety of tests in different environmental areas all over the world--thus, the Antarctic, the most unique environmental area in the world.

<u>Summary</u> - This Antarctic Task Force is made up of all branches of the military service and civilian scientists. Here where the dangers are ever present, and every man a buddy, unification is at its best. These men continually face the dangers of whiteouts, frostbite, crevasses, weather, etc., which means that one can never relax. Relax once and the wall of security you have so painstakingly erected about you may give way without warning.

The past reminds man that though he has harnessed much of nature by his ingenuity, he has not harnessed all; old mother nature, with her weather, controls all operations in Antarctica. However, with all the dangers and difficulties, antarctic operations have been successful. The military has advanced itself in polar operations and at the same time served science and the world.

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U. S. ARMY TRANSPORTATION BOARD'S ENVIRONMENTAL PROGRAM FOR FY62

Major Burns I. Perfect

U. S. ARMY TRANSPORTATION BOARD

Fort Eustis, Virginia

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U. S. ARMY TRANSPORTATION BOARD'S ENVIRONMENTAL PROGRAM FOR FY62

Part of the Transportation Board's mission is to provide transportation support for military activities in difficult environments and to conduct operations leading to improvement of difficult-environment transportation capabilities. To accomplish this portion of the mission, the following projects are scheduled for FY62:

SWAMP FOX - Project TCB-61-051-EO

SWAMP FOX is an extended logistical carrier operation in virgin tropical rain forest from Chepo to El Real through the Darien Gap of Panama. A composite task group of technical service and scientific personnel, with minimum engineering support or preparation, is attempting overland movement during the rainy season with the objective of improving U. S. Army transportation capabilities in tropical environments. (Period - July to October 1961)

PR&DC LIAISON - Project TCB-61-065-EO

The PR&DC project calls for a liaison visit by a U. S. Army Transportation Board member to PR&DC in Thule, Greenland, to observe and report on all newly developed equipment and techniques presently used in arctic operations and to evaluate the Passive Trail Marking System developed by General Precision Laboratories, Pleasantville, New York. (Period July through August 1961)

TF 43 TOPO (62) - Project TCB-61-066-EO

The U. S. Army Transportation Board will provide helicopter (HU1B) support for Navy Task Force 43 during Operation Deep Freeze (62). The purpose of aviation support by the Transportation Corps is to assist the National Science Foundation and the U. S. Geological Survey in mapping the area from Cape Adare through McMurdo Sound to Beardmore Glacier. This operation encompasses approximately 125,000 square miles

and will entail approximately 300 flying hours. An additional objective of this project is to familiarize Transportation Corps pilots with antarctic flying techniques and thus further increase the inventory of "antarctic-qualified" pilots within the Transportation Corps. (Period - September 1961 through March 1962)

FAR NORTH (RECONNAISSANCE) - Project TCB-61-070-EO

The objective of Project FAR NORTH is to locate a possible overland route which will permit the economical resupply of selected DEW Line stations from the interior, to include: avenues of approach, staging areas, routes of march, types of trail marking needed, resupply points, possible obstacles, climatic or weather conditions, vegetation, and trafficability.

GREAT BEAR - Project TCB-61-073-EO

GREAT BEAR is a USCONARC Army field maneuver in Alaska during the winter season 1961-1962 involving battle-group size units. A task element of the U. S. Army Transportation Board will provide additional logistical "close-in" support vehicles, both wheeled and tracked, to include commercial off-road type vehicles utilized by civilian industry. An additional purpose will be to gain experience and test techniques under subarctic conditions not encountered during WILLOW FREEZE. (Period - January 1962 through March 1962)

USAF RESUPPLY - Project TCB-61-128-EO

Project USAF RESUPPLY comprises a logistical resupply mission to remote Air Force outposts such as Bettels and Indian Mountain in Alaska. The logistical convoy will be headed by the Overland Train Mk I; appropriate tracked and wheeled off-road vehicles will be included for evaluation of their utilization and capabilities in subarctic terrain. (Period - December 1961 through March 1962)

DRY GULCH - Project TCB-61-143-EO

DRY GULCH, a desert navigation operation conducted by a squad from a Medium Truck Company at Camp Irwin, California, has as its purpose the developing of techniques for desert environment and the obtaining of data on desert navigational problems that will be encountered in subsequent desert operations scheduled for Calendar Year 1963. (Period - May through June 1962)

TRAIL TREK (62) - Project TCB-61-147-EO

> The Chief Navigator (surface) to Navy Task Force 43, Antarctic, will be provided by the U. S. Army Transportation Board. Extended surface navigation operations will be conducted from Little America V to Byrd Station, to include re-marking and re-aligning the present Army-Navy Drive; filling all crevasses that will endanger future operations; and acquiring operational data for improvement of operating techniques in polar environments. (Period - October 1961 through January 1962)

Consideration has been given to conducting environmental operations within CONUS rather than outside CONUS whenever the environmental conditions can be reasonably duplicated or when the primary purpose of the operation is the test and evaluation of equipment.

Activities in difficult environments have been aimed at the solution of transportation operational problems which interpose themselves in the accomplishment of planned missions and the support of future organization concepts.

In the programming of its activities, the U. S. Army Transportation Board has emphasized study, investigation, and test in those areas in which no, or very limited, operational capability has been attained to date. Swamps and jungle regions as well as summer muskeg terrain are examples of such areas.

Liaison has been established with appropriate authorized military and civilian agencies engaged in research and test activities in difficult environments.

Maximum utilization has been made of opportunities to test and evaluate TC equipment in connection with any environmental operations.

THE APPLICATION OF MURPHY'S LAW TO ENVIRONMENTAL RESEARCH

Colonel Robert B. Harrison

President

U. S. ARMY TRANSPORTATION BOARD

Fort Eustis, Virginia

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THE APPLICATION OF MURPHY'S LAW TO ENVIRONMENTAL RESEARCH

In any consideration of environmental research, the military applications of the disciplines involved must be carefully examined. Among the most vexing of these applications is the provision of an adequate antidote to the problem set forth in Murphy's law.

Murphy's law has been stated by many generations in many tongues. While I may not express it in the same terms that you would, I am confident that you will recognize it and agree that the problem exists and is worthy of careful consideration.

Briefly:

> "If there be but one way in which an item can be mishandled, or a single, obscure manner in which it can be damaged, issue the item to the operator in the field and he will, inevitably, find this one fault."

There is an inevitability in Murphy's law that holds a sinister fascination for the designer, the manufacturer, the logistician, and the user. There are those who suspect that it holds the same fascination for the ultimate operator, since this inevitability has seldom been challenged and its veracity too often sustained. Why else would the very word "foolproof" appear in our vocabulary?

In its essentials, environmental research is the determination, empirically, experimentally, or through actual experience, of the actions or reactions resulting from the exposure of resources (personnel and/or materiel) to varied environments. In order that conditions of exposure may be controlled and calibrated to insure accurate records, and to reduce expenses believed to be inevitable when resources are moved to the desired environment, great emphasis has been placed on the artificial creation of environment. In certain instances we have no other recourse than the use of the artificial; the state of the art is not yet such that we can physically expose resources to the actual environment of the moon or of the planets. For the moment, we must be satisfied with an empirically calculated environment created in the laboratory and test chamber and the observations resulting therefrom; the relationship of this environment to the actual must await verification at a later date.

I bring before you today the contention that environmental operations, operations during which the resource is moved to the actual environment, offer the only final, definitive answer to the problem posed in Murphy's law and that this answer cannot be successfully insured by any other means now existing. The theoretical study of environmental effects, the extensive and laborious testing of resources under controlled environmental conditions within the laboratory or test chamber, provides useful answers and should never be neglected. But the ultimate answer can be insured only by complete exposure of the items, or their components, to the actual field conditions to be encountered. And such field conditions must include use of the item by typical operators, or groups of operators. Any lesser exposure will result only in the failure to identify the "one fault" which is the crux of Murphy's law. This fault may then remain unidentified until the crucial moment when its discovery will best induce failure. Inevitably this will be the precise moment when failure can least be tolerated.

Strangely, there has been a tendency to regard environmental research as applying only to the environmental extremes--the Arctic, the desert, the swamp, or the tropical jungle. The vast majority of our resources are regarded as being completely compatible with a temperate environment; relatively few are designed specifically for successful operation under the extreme environments. Existing military policy states that type classification of an item of military hardware will not be delayed pending exposure to environmental extremes unless such a requirement has been expressed in the military characteristics pertaining to the item. This is an exceptionally dangerous tendency insofar as it leads to a disregard of Murphy's law and the curious sequence of events whereby military items of hardware are type classified and placed in production before such items are placed in the hands of troops for "troop test" and the application of Murphy's law.

There is a school of thought, endowed with the mantle of sagacity by unchallenged years of existence, which holds that incipient faults are completely susceptible to solution in the controlled environments of the laboratory or climatic chamber. This approach has been imbued with the cloak of respectability by the high percentage of cases wherein solutions have been achieved in this manner. However, the tender loving care of the research and development engineer, and even the supposedly objective and impartial observations of the test engineer, does not subject the procedure, or the item, to the rigorous faultfinding which can only result from the application of Murphy's law.

Quite aside from the human element, which provides the crucial ingredient of the unsuspected during environmental operations, conditions in

the field normally cannot be precisely duplicated in the laboratory. The requirement for controlled and identifiable conditions precludes such duplication. The majority of the factors encountered in the field can indeed be duplicated, or induced, in the environmental chamber, but it is seldom that all field conditions are reproduced simultaneously and in the precise formula which prevails under nature's quixotic pattern. Subjected to a single simulated environment, or to a variety of simulated environments in sequence, a procedure or item may respond outstandingly and appear to possess all the desired attributes. Exposed to these same conditions in their natural proportion and interrelationship, and actually used under such an environment by an individual interested essentially in basic self-preservation, these same procedures or end items have an unacceptably high projection of unanticipated failure.

The existing inclination to maximize use of artificially created environments appears to result from (i) the desire to control and calibrate so that accurate records may be insured, and (ii) the expense supposedly involved in moving the resource to the environment. Of these two, we submit that the former can be overcome through adequate planning and the intelligent application of modern data-acquisition procedures. The latter appears to be the more influential of the two, mainly on the basis of economy--a phrase which possesses great appeal and which has been overused as justification for more than one extravagance.

Gestalt psychologists emphasize that life itself is not built up of tiny units of association, or specific connections or reflexes, but that it operates in larger units. When we look at a person, we do not see eyes, nose, and lips separately, and then add them together. Rather, we see the face as a whole. It is not too farfetched to apply this same principle to environmental research, and through its application we can insure the application of Murphy's law and the consideration of the results achieved through such application.

To use a somewhat hackneyed phrase, the environmental researcher must constantly take a look at the "big picture" It is not sufficient to examine the minutiae and deduce that satisfactory performance of components guarantees equally satisfactory performance of the whole, nor to examine elements of an entire environment and conclude that exposure to the actual environmental conditions in the field will sustain acceptability. In the face of this insufficiency, how can we insure the application of Murphy's law and counter the claims of uneconomical operations and scientifically unacceptable data?

A notable approach has been made to providing answers to the problems through the existence of Yuma Test Station in Arizona and the recent opening of technical service test activities at Fort Wainwright, Alaska. USCONARC provides field facilities through its various boards; however, the work of these organizations is aimed towards the field army and its equipment and only in passing contributes to examination of other military items. The technical services themselves operate various types and complexities of proving grounds, test facilities, etc.

However, in all these instances the activities tend to be formalized engineering testing, service testing, or endurance testing installations. And, with the exception of Yuma (which offers a desert and hot weather environment) and Wainwright (which offers subarctic and muskeg environments), other installations are temperate in nature and largely controlled in environment.

Few of these boards and activities can successfully apply Murphy's law. Weather, terrain, project personnel, and mental approach preclude its application. The simple fact that individuals assigned to these facilities are well qualified to operate, observe, report, and analyze militates against the problems of Murphy's law being encountered. Controlled observations, carefully made in strict accordance with the approved plan of test or test agenda, will be successfully recorded, and from these observations, data will be attained which will assist in the development cycle. But the unsuspected fault, the single fault induced by the man in the field, will too often remain undetected.

It is our contention that the joint environmental operation, conducted in the field under actual field conditions far removed from the laboratory, the test facility, the supply base, the maintenance backup, or the comforts of the post, camp, or station, provides the only reliable means for applying Murphy's law, and that such operations, jointly conducted on a continuous basis in varied environments, can be accomplished economically and with maximum benefit to all elements of the Armed Forces.

We of the Transportation Board experienced the application of Murphy's law during our Operation TROPICAL WET, conducted in Panama during October and November 1960. This operation was a joint venture in a limited sense, in that Signal Corps and Quartermaster Corps provided participating personnel and a civilian organization under contract to the Ordnance Corps likewise took an active part. Let me quote from the letter report submitted by the Signal Officer, USACARIB:

"The communications link between the Chepo, R de Panama, base camp and test unit en route to Pintupo, R de Panama, was not successful due to a number of problems. Equipment planned for this link was a jeep mounted AN/GRC-19 netting with a similar unit. About five miles east of Chepo all movement of wheeled vehicles was halted because of mud which prevented the jeep mounted radio from continuing. Consequently, an AN/GRC-9 was hurriedly mounted in a Weasel and Voice or CW communications was used between the test unit and the base camp (AN/GRC-9 and AN/GRC-19). This did not work due to the hasty "field expedient" installation of the AN/GRC-9 and TREOG radio operator's inexperience in operating under adverse conditions, frequency instability and jungle cover of test unit."

I am confident that you can identify the application of Murphy's law in this short segment of the overall report. In our operation SWAMP FOX, presently underway in the same tropical jungle environment, we have a vastly enlarged technical service and scientific organization representation, and we are confident that the application of Murphy's law will be examined and evaluated in detail. Indeed, the provision of answers to the problems raised by this law may well be essential to the survival of individual members of the operation's task group.

We make no claim that our board should be either the sole or the major proponent of environmental operations in the field. Inasmuch as basic transportation of personnel or materiel under difficult environmental conditions is a keystone of our charter, we believe that we have an interest in any such operation. But we freely extend to all elements of the Armed Forces, and to our allies of the ABC nations, an invitation to join with us, cooperatively, in the conduct of environmental operations. Conversely, we have high hopes that other organizations conducting like operations will extend to our board, and our Corps, an invitation to participate with them.

We do desire to place before you at this meeting our strong plea that environmental operations in the field be conducted on a logical, coordinated, basis both in temperate and extreme environments. Only through the medium of such operations, conducted under the surveillance of qualified agencies by average personnel of the military forces, can the application of Murphy's law to environmental research be examined, and only through such examination and detailed consideration of the results attained can we insure that the man in the field will not find the one unsuspected fault at the precise moment when victory or defeat lies in his individual hands.

ARCTIC, DESERT, AND TROPIC TEST OF NODWELL 5-TON VEHICLE

John H. Dye

U. S. ARMY TRANSPORTATION BOARD

Fort Eustis, Virginia

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ARCTIC, DESERT, AND TROPIC TEST OF NODWELL 5-TON VEHICLE

INTRODUCTION

Despite the fact that the world has unlimited roadways, airways, and waterways, with remarkably effective vehicles for providing transportation over these, there still exist immense areas which resist or defy conformity to the generally advanced stages of modern transportation media. The most formidable areas lie at the extremities of civilization, and include the snow, ice, muskeg, and frozen terrain of the polar regions; the mud, marsh, rivers, and dense vegetation of the jungles; and the sand, dunes, playas, and washes of the deserts. Environment often allies with rugged terrain to thwart effective operations of the vehicle designed for terrain alone.

Even in the face of such odds, eventual penetration of and controlled mastery of transportation through these areas are assured because of military tactical or logistical needs, or commercial economic incentives. Whereas commercially developed media tend to concentrate on a single transportation barrier, military development seeks the multipurpose vehicle, one that is capable of traversing several, and ideally all, terrains and environments.

Design of dual-purpose and special-purpose vehicles has met with creditable success in such instances as amphibians, from the World War II DUKW to the current BARC and LARC's; 4-wheel-drive vehicles for traversing off-road terrain; and special tracked or large-tired vehicles for snow, marsh, or other particular terrains. All such vehicles perform well within their design parameters; but because of practical and economic considerations, they fail when they are envisioned for use over additional terrains. In using single of dual terrain oriented design, certain barriers may be bypassed by means of selective routing, practical trail blazing, or terrain improvement, at the expense of additional time and equipment.

In view of the lack of definite standards by which to classify the diversity of terrain encountered, even in generally known categories such as muskeg or sand, because of random occurrences of stumps, logs, stones, or variable profiles, it is extremely difficult to accurately apply known locomotion theory to the development of a multipurpose vehicle. Evaluation by the Military of commercial equipment, usually developed for traversing a single difficult terrain, with a view to multiterrain application has led to

the discovery of potentially effective multipurpose vehicles. By test of a vehicle designed specifically for one terrain, in other correlated environments, it is possible to determine limitations or adaptability or to suggest redesign trends to effect the desired degree of versatile terrain mobility and environmental endurance. This consequently may result in reduction of military research and development cycles since testing can determine suitability of vehicular transportation capabilities directly or by slight modification. This presumes the need for far-flung test sites of representative difficult terrains and environments where locomotion theory and actual trials can combine to determine empirically actual performance data.

One vehicle which has indicated the success of multienvironment testing is the Nodwell RN110 Cargo Transporter, manufactured by the Robin-Nodwell Mfg. Ltd. of Calgary, Alberta, Canada (see Figure 1). This transporter was designed specifically for operation over muskeg, a formidable subarctic terrain comprising approximately 500,000 square miles of the Canadian northland. Its design was prompted by the interest of oil companies in conducting extensive explorations for oil in this region. Dependence on conventional vehicles required halting of operations after summer thaw of the permafrost because these vehicles were then unable to haul heavy drilling rigs and supplies cross country to drilling sites. During winter months, the frozen terrain can be negotiated by wheeled vehicles, assisted by a dozer to blaze and improve trails. In 1951, Robin-Nodwell began development of a vehicle capable of transporting heavy cargo over the vast muskeg bogs on a year-round basis. A family of low-ground-pressure, tracked vehicles has now been developed, ranging in cargo capacity from 2,100 to 24,000 pounds.

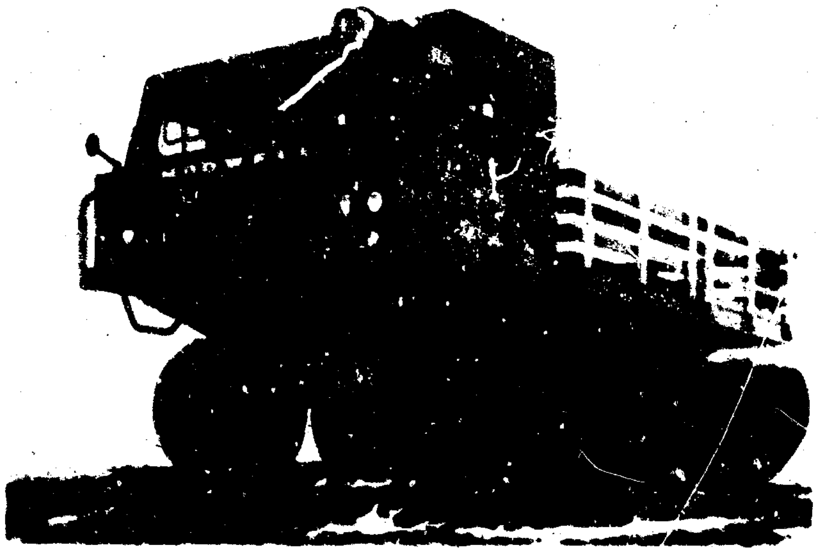

Figure 1. Nodwell RN110 Cargo Transporter.

COMMERCIAL OPERATIONS

By 1960, the Nodwell transporters had established notable recognition for their capability and dependability in maintaining continuous work schedules in arctic and subarctic operations, employed by such concerns as:

(a) Western Geophysical of America, Anchorage, Alaska, employing 13 vehicles (RN75 and RN110, of 7,500 and 11,000 pounds rated capacity, respectively) in Alaska.

(b) Ontario Hydro Commission, employing one RN75 in northern Ontario.

(c) Northwest Telephone Company, Vancouver, British Columbia, employing one RN110 in British Columbia. The vehicle was reported to be operating in snow up to 15 feet deep and on slopes with grades of up to 17 percent.

(d) Shell Oil Company, using three RN200's (20,000 pounds rated capacity) and several lighter models in the movement of oil drilling rigs to drilling sites over muskeg in northern Alberta.

(e) Imperial Oil Company, using lighter models in seismographic exploration in northern Ontario.

(f) Lake Phelps Farms, Inc., Pike Road, North Carolina, using 13 vehicles (RN21 - 2,100 pounds capacity, RNS - skidder model with dozer blade, and RN110) in the conversion of 150,000 acres of virgin swamp land to farm land.

(g) Humble Oil Company, operating in Louisiana swamps and using metal or rubber pontons to convert the vehicles to floaters.

Shell Oil Company reported that the tracks on their vehicles performed in excess of 6,000 miles, with occasional grouser replacement, over snow, ice, mud, clay, rocky soil, and muskeg. The RN75 achieved speeds of 30 to 35 miles per hour on-road, but was unable to exceed 20 miles per hour off-road. Shell experienced maintenance difficulties with gasoline engines on the RN200; therefore they converted to diesel engines, which gave better performance and availability. Shell also noted difficulty of night maneuvering through muskeg, where the operator must exercise

selective routing to avoid holes, logs, and stumps. Vehicles lacked spotlights for trailing and floodlights for cargo handling. Shell averaged 8,000 miles per vehicle over a 2-year span. The RN200 carried loads of up to 15 tons without serious strain. On one occasion, a vehicle in operation was weighed and found to be carrying 10 tons of mud on its cargo bed and undercarriage.

In the Lake Phelps Farms' project, the operation consists of dividing off rectangular tracts of farm land by drainage canals and feeder ditches to the Pungo River. The earth has deep, organic, heavily rooted vegetation to depths of 3 to 10 feet, over underlying sand hills, with sparse to heavy surface scrub pine and logs from many previous burnings (see Figure 2). The soil is very moist and of high acidic content. Much of the area has standing or slightly subsurface water with heavy sulphuric content. The object of the operation is to drain, plow, and aerate the area, mix underlying sand with the organic vegetation, and neutralize the soil by the addition of lime. Generally flat, with very rough surface, the terrain is similar to subarctic muskeg. As a result of previous burnings, trees present no particular obstacle. However, sunken logs and roots are numerous.

Lake Phelps Farms uses RN110's in pulling plows weighing 7,000 to 8,000 pounds, with no cargo bed on the transporter but with concrete aggregate blocks as ballast on the vehicle frame varying in weight from 1,000 to 2,000 pounds (see Figure 3). Operators disagree as to the proper amount of ballast for most effective plowing. The vehicle pintle was inadequate for this rigorous towing service and was replaced by a special towbar modification. RN110's are also used for spreading lime on the tracts, at rates of up to 2-1/2 tons per acre (see Figure 4). Steel hoppers, which are mounted on the vehicle frame, carry loads of 6 to 8 tons (up to 3 tons over rated capacity). Overloading has created no particular problems. Model RNS vehicles (designed as logger-skidders) fitted with dozer blades are used for brush clearing and levelling. RN21's (2,100 pounds capacity) with flat beds are used for hauling sacked lime and general cargo and for field contact work.

Nodwells have been in use by Lake Phelps Farms since January 1961, the oldest vehicle having in excess of 1,000 hours operation as of this writing, working normal 10-hour days, 5-1/2 days a week. The amount of maintenance required to date has been relatively small. Some difficulty was experienced in maneuvering. No troubles have occurred with differentials, sprockets, tires, or bearing inserts. No tracks have been replaced, only some grouser bolts. Fuel consumption on the RN110's pulling plows and travelling at full throttle at 3-1/2 to 4 miles per hour runs about 6-1/2 gallons per hour.

Figure 2. Organic Terrain at Lake Phelps Farms, North Carolina.

Figure 3. Plowing Operation at Lake Phelps Farms.

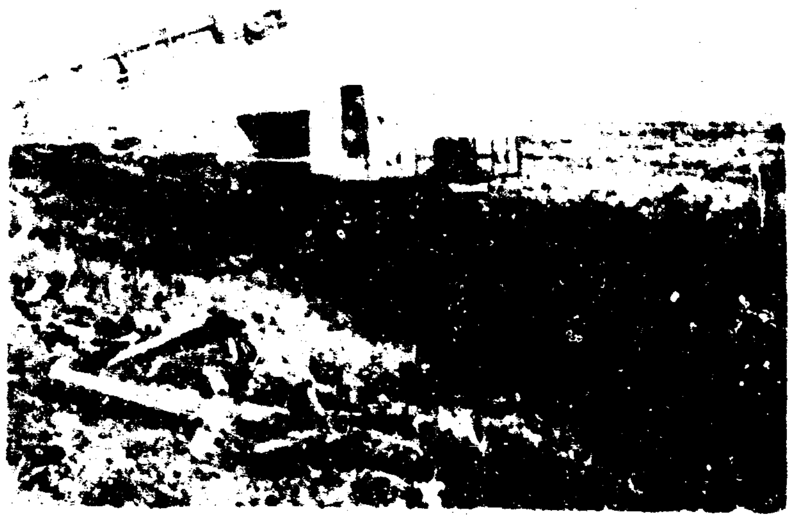

Figure 4. Lime Spreading Operation at Lake Phelps Farms.

Many types of vehicles were tried by Lake Phelps Farms prior to selection of the Nodwells. Wheeled vehicles generally were not successful because of their high ground pressure. Steel-tracked vehicles with ground pressures in the order of 6 to 9 p.s.i. failed because they bogged down. Also, they compacted the soil to such an extent that mixing and aeration could not be accomplished; thus, ponds of water were left on the soil. For effective working, it was found that ground pressures should not exceed 3 p.s.i. Ditchers, for digging the canals, are steel-tracked vehicles, but these are transported to operation sites at ends of roadways by a special lowboy wheeled trailer and are operated over airfield matting as they progress. Even with this precaution, ditchers have submerged 3 feet during operation.

CHARACTERISTICS OF THE RN110

The RN110 is a 4-axle, two-tracked carrier with a clear or stake-side cargo deck area of 7 feet by 12 feet and a cargo capacity of 11,000 pounds. The rubber-covered nylon-cotton track belts are connected by spring steel grouser bars bolted to the belts. Open center portions of grouser bars are curved to fit standard pneumatic tires on the bogey wheels, 4 wheels per track. Rubber inserts for grousers are available for highway operation. Track tension is manually adjustable by bolt action or by an optional grease cylinder. The rear sprocket drive of each track provides tension in the tracks upon ground contact. Each wheel has an independent crank arm with torsion spring suspension, which permits individual vertical movement. The vehicle is designed for all-weather, year-round mobility in muskeg, bush, bog, gumbo mud, snow, swamp, and rugged terrain, with the ability to negotiate 60-percent grades and 30-percent side slopes. Speed range, by optional gear ratios, may be 12 to 25 miles per hour. Steering is accomplished through levers that hydraulically activate a controlled differential equipped with outer planetary reduction gears. Braking is accomplished by applying both steering levers simultaneously. A disc-type, hand-operated emergency brake is provided on the drive shaft.

An engine, optional gasoline or diesel, drives through a mechanical forward and reverse transmission, a drive shaft, and a controlled differential to outer planetary reduction gears built into the hubs of the drive sprockets. The vehicle chassis uses a backbone frame composed of two parallel, Z-bar, deep longitudinals boxed together by welded channel cross frames, an arrangement permitting maximum track/vehicle width ratio. Open or closed operator's cab is optional. General construction is steel, with marine plywood cab deck and hardwood cargo deck. Construction is practical and

austere. Accessory equipment includes a front-mounted winch, a rear towing pintle, and a cab heater. The cargo deck configuration is versatile, including optional flat bed, stake body, camp or sleeper units, or clear frame for hopper, dump, or drill-rig mounting. General specifications are as follows:

Net weight	10,580 lb.
Designed payload	11,000 lb.
Gross weight	21,580 lb.
Length	19 ft. 4 in.
Width	8 ft. 11 in.
Height (to top of closed cab)	8 ft. 0 in.
Cargo deck area	7 ft. by 12 ft.
Ground clearance	16 in.
Fording depth	36 in.
Turning radius (inside)	103 in.
Track width	40 in.
Track area (zero penetration)	10,720 sq. in.
Ground pressure	
Loaded at zero penetration	1.68 p.s.i.
Loaded at 10-in. penetration	2 p.s.i.
Speed	15 m.p.h. at 3,800 r.p.m. (12 to 25 m.p.h. optional)

Gradeability	
Forward	60%
Side slope	30%
Fuel capacity	44 gal.
Cruising range	60 mi.
Engine	Ford V-8, gasoline, 292 cu. in.; or GMC 3-53, diesel
Electrical system	12-volt
Tires	7.50 by 20, 12-ply
Track belts	Rubber-covered nylon-cotton, 15-inch wide, 4-ply, with heat-treated spring steel grousers
Drive sprocket	16-tooth rubber and steel construction, consisting of two rubber moldings with a steel center overload and hub section

SUBARCTIC OPERATION

Initial military interest in and test of the RN110 occurred in the RN110's native environment, where it was used as a general-purpose cargo carrier for logistical support of a tactical winter exercise, OPERATION WILLOW FREEZE, in the Alaskan theater in January and February 1961. Five vehicles were used to transport and tow 295,930 pounds of cargo during 20 support missions, travelling a total of 1,863 vehicle miles and 1,017 vehicle hours over off-road subarctic winter terrain (see Figures 5 through 8). Although the RN110 was designed as a cargo carrier, it was found to be effective in towing a Mark I Rolling Liquid Transporter of 1,000-gallon capacity. During this operation, mechanical reliability resulted in 9[illegible].3 percent availability of the vehicle.

As a cargo carrier, typical loads transported by one vehicle included 250 cases of C rations, 22 POL drums (55-gallon capacity) standing on

Figure 5. RN110 Loaded With Oil Drums and Towing a 10-Ton Rolli-Trailer.

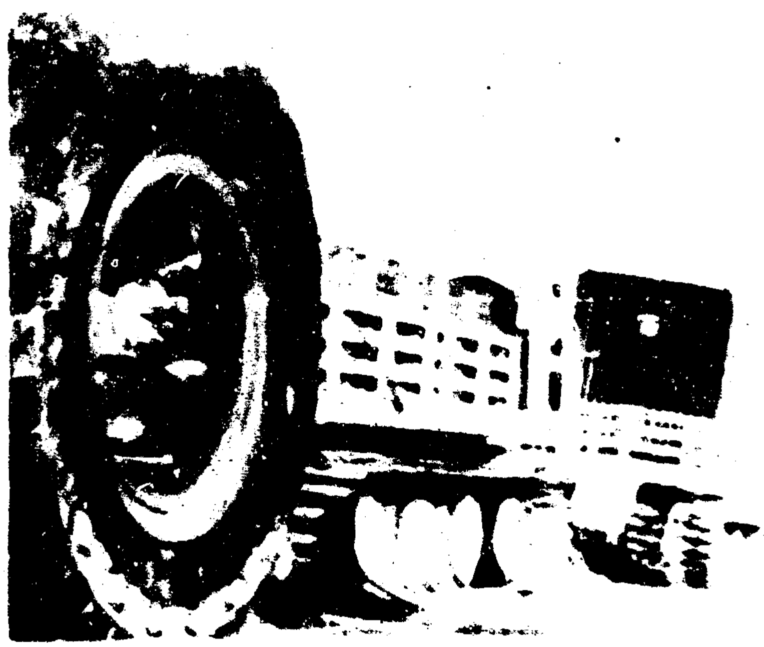

Figure 6. Caravan in Snow, Towing Rolli-Trailer and Carrying Oil Drums and CONEX Box.

Figure 7. Operation Over Unimproved Subarctic Snow-Covered Terrain.

Figure 8. Breaking Trail Through Light Forest in Subarctic.

end, 30 drums pyramided, or one CONEX container. The flat-bed configuration did not prove to be the optimum possible because its ability to transport bulk cargo was limited. It was found that the rated cargo loading of 11,000 pounds could be exceeded without apparent detriment. A single vehicle could haul up to 2,155 gallons of fuel. Exceptional mobility was demonstrated in towing RLT's over broken trails, unimproved roads, and tank trails and in negotiating side slopes of over 30 percent. In soft snow of an 18-inch depth or more, drag of the RLT made steering ineffective, and slippage of the track caused snow to build up ahead of the RLT and virtually stalled the vehicle. Difficulty was compounded by the inability of the Mark I RLT to track the RN110. By backing and ramming, the combination could proceed, but it lacked traction over grades in excess of 10 percent. Snow cleats were not used. Their use, and mating with the Mark II RLT, which will track the RN110, may overcome this barrier.

On cross-country maneuvering, the RN110 broke trails through forests with trees of up to 6 inches in diameter and forded streams to 43-inch depths. Ice to a minimum thickness of 16 inches was traversed. Selective routing was used to avoid excessive slopes, heavy forests, logs, large roots, and unfordable river. Snow up to 8 feet deep was traversed with ease. Penetration in very soft powdered snow varied from 6 to 14 inches. Traction on ice and icy slopes was inadequate, but may be correctable by adding cleats to the grouser bars. The maximum governed speed of the vehicle was 15 miles per hour; however, cross-country speeds were generally 7 to 9 miles per hour, restricted by roughness of terrain rather than by lack of power. Temperatures to -34°F. were encountered. Head-bolt heaters, 750-watt, were used.

The amount of vehicle operating time during Operation WILLOW FREEZE was too small to entail much maintenance, the only major failure being a radiator leak, which was possibly caused by faulty soldering. Two of the five vehicle pintle hooks broke during the towing of RLT's, indicating underdesign for this purpose, or limitation to approximately 2,000 pounds drawbar pull. Several modifications were recommended, such as enlarging the fuel tank, widening and strengthening the cargo bed, and installing a larger heater.

DESERT EVALUATION

One RN110 was subjected to strenuous desert operations at Yuma, Arizona, over a 30-day period in April and May 1961 to determine its durability, drawbar pull, rolling resistance, gradeability, and other performance characteristics while operating over various desert terrains (see Figures 9 through 12). Tests were run with a fixed 11,000-pound load over terrain

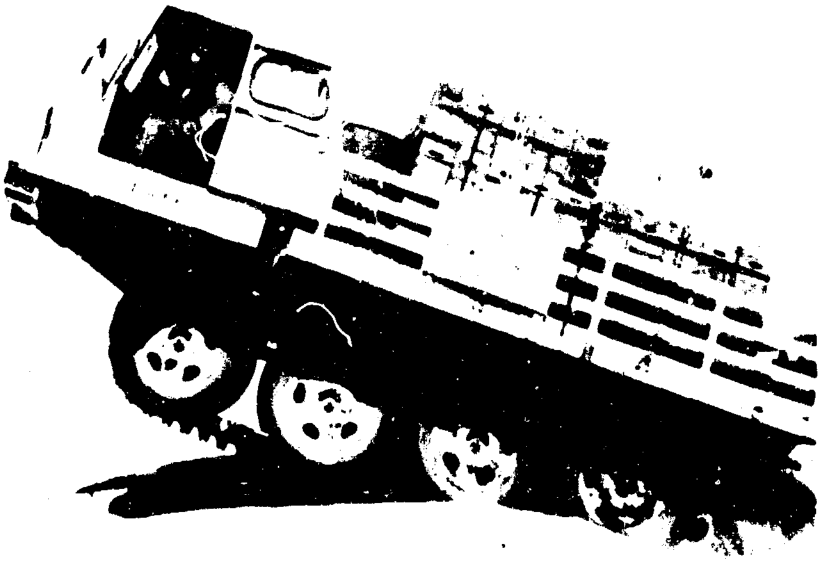

Figure 9. Breaking Over Top of Sand Dune at Yuma, Arizona.

Figure 10. Climbing a Sand Slope.

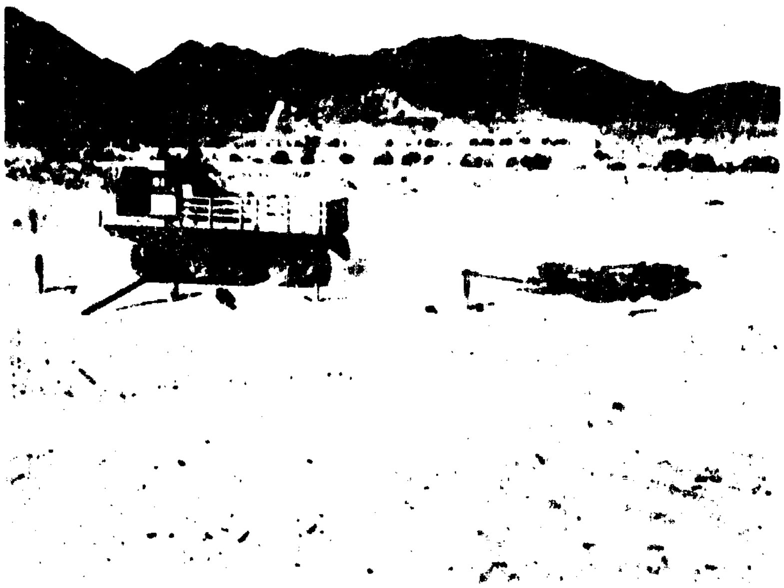

Figure 11. Determining Drawbar Pull in Soft Sand.

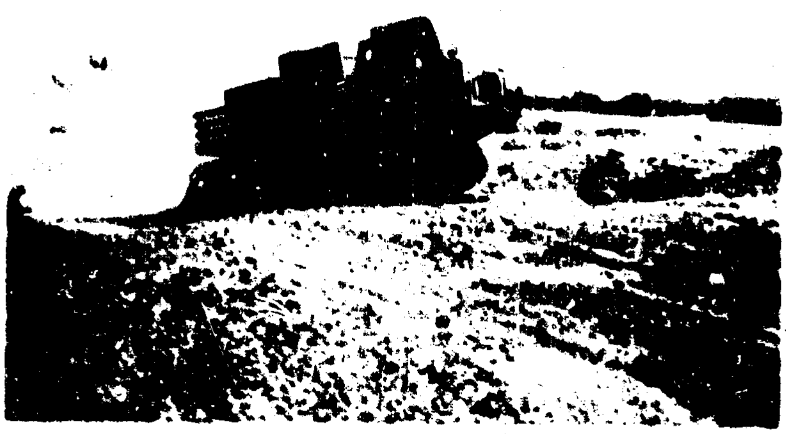

Figure 12. Operation Over Desert Gravel Wash.

features such as desert pavement, gravel wash, badlands, sand plains, and sand dunes. Temperatures ranged between 49° and 101°F. The selected vehicle completed 160 hours of testing.

The vehicle performed well in terms of cargo and towing capabilities, fuel consumption, and low maintenance during the tests. However, subsequent teardown inspection disclosed a toll in wear and abrasion exacted on a vehicle out of its native element. This included excessive wear on the fiber half-bearing inserts under the wheel axles; worn wheel bearings, rubber drive sprockets, and tire sides; and inoperation of the hydraulic master cylinder due to lack of sand protection. Other malfunctions occurred, such as cracks in frame stress points, bending of axles, and excessive wear on brake bands and drums. These effects were not unexpected, and do not comprise serious defects in adapting the vehicle to desert operation.

Drawbar pull in soft sand was determined to be 8,400 pounds with the vehicle empty and 14,000 pounds loaded, without the use of cleats. Grades up to 36 percent over sand dunes were negotiated under full load, with slippage as great as 85 percent. Speed runs with an 11,000-pound fixed load and with a 6,400-pound RLT tow averaged 11 miles per hour; without tow, nearly 13 miles per hour. Fuel consumption was 1.4 miles per gallon under load at 4.2 miles per hour. Oil consumption averaged 1 quart in 10 hours of operation at 3,500-3,800 r.p.m. Due to the rigid springing suspension of the vehicle, cargo had to be well secured on cross-country operations to prevent its shifting when the vehicle pitched forward as it broke over a ridge or mound.

Extreme racking caused 33 fractures in the narrow main frame, none of which caused operations to cease and all of which were reweldable. Stronger, deeper frames have already been incorporated in later models. Play, backlash, and wear in excessive amounts occurred in steering, braking, and drive systems; the cause was the rigorous and constant maneuvering conditions. All defects were capable of being adjusted or repaired to acceptable limits. Certain observations disclosed areas in which design could be improved for greater durability in desert operations, such as adding seals or changing the material of wheel axle inserts. Vehicle range in desert operation (40 miles) was less than that in previous subarctic tests. Radiator protection also was found to be advisable to preclude clogging of the core by desert debris.

TROPIC EVALUATION

As of this writing, one RN110 is undergoing test in a rugged, tropical rain forest environment--the virgin Panamanian jungle in the area between Chepo and Santa Fe. Vehicle performance is being determined in respect to mobility and cargo transportability through thick vegetation, over muddy swamp plains, across fordable rivers and streams, and over hills and varying terrains, with exposure to heat, humidity, fungus, and rainfall of the tropics. The projected distance of the jungle trek is about 120 miles, 84 miles having been covered to date. The vehicle is being operated in conjunction with other selected tracked and rubber-tired vehicles.

From the roadhead at Chepo, the caravan plied cross-country, following a narrow muddy trail and fording a shallow (3-foot depth) river (see Figure 13). Several vehicles mired in the thick clay-mud, and the RN110 was used for ecovery (see Figure 14). The RN110 was loaded to rated capacity and was one of two vehicles capable of towing a Rolling Liquid Transporter through the mud encountered.

Figure 13. Towing Vehicle Through Mud.

Figure 14. Immobilized in a Ravine.

During a 27-hour, 15-mile thrust across the marsh plain between Chepo and the Canita River, sticky mud to a 4-foot depth was encountered in heavy woods with an undulating, deeply rutted trail. The RN110 slipped into a gorge and was winched free (see Figure 15).

Figure 15. Fording a Stream.

It also threw its left track while climbing and twisting over a 25-percent slope; the track was loose and apparently struck a log or stump. Replacement and track tightening corrected the trouble. The RN110, although the heaviest vehicle in the caravan, was one of the two best performers in this type of terrain.

Under the jungle canopy, mobility became more complex because of additional obstacles of side slopes, inclines, trees, and dense vegetation. In this terrain, the RN110 proved to be a dependable "work horse" for the convoy, negotiating uphill slopes of up to 42 percent under full load. Performance on slopes varied depending on moisture content of the soil, moisture content being critical on side slopes because of the vehicle's tendency to slide. Winching was required occasionally under such conditions. For crossing nonfordable rivers, ferries were made to float "nonswimmers" such as the RN110 across.

At the two-thirds point of the jungle penetration, the RN110 was one of 6 vehicles remaining of the original 14. Fuel consumption averaged 1 gallon per mile, and no engine oil was added. Two quarts of transmission oil were consumed. Mechanical failures included the thrown track previously described, a broken drive shaft, and bolts broken off the drive sprocket. Repairs were accomplished in each instance, thus permitting operation to continue. Steering qualities proved to be seriously deficient when the RN110 was towing equipment such as the Rolling Liquid Transporter. Steering was satisfactory when the RN110 was not towing other equipment and was loaded to capacity. The closed cab on the test vehicle contributed to cab temperatures ranging from 10 to 15 degrees above the ambient temperature, which caused the operator to experience undue fatigue. However, open cabs are optional for the vehicle.

Full details of the RN110's jungle performance will not be available until the expedition is completed, recorded, and studied. Performance to date has indicated that the vehicle has a definite capability for traversing jungle terrain.

FUTURE PLANS

Future plans call for additional tests in arctic and desert environments to retest modified features and to investigate the rather unsuspected capability of the vehicle for prime-mover applicability, especially when fitted with track cleats. Improvement of highway trafficability

also will be investigated. Floater provisions for the vehicle are being studied by the manufacturer, which will further add to terrain versatility of the vehicle.

Testing to date has not indicated that the penalty for added terrain ability is too great or that additional versatility would be impractical.

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STATUS REPORT - OPERATION SWAMP FOX

Lieutenant Colonel Merle R. Dawson

U. S. ARMY TRANSPORTATION BOARD

Fort Eustis, Virginia

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STATUS REPORT, OPERATION SWAMP FOX

Operation Swamp Fox is a combined U. S. Army technical services environmental project being conducted in the virgin jungles of Panama.

Mission: The U. S. Army Transportation Board will form the nucleus of the command and transportation agency for a combined technical services team of specialists who will study the tropical environment of Panama as it affects the operations and/or products of their particular service.

Execution: Extended operations will be conducted in the virgin jungles of Panama from the town of Chepo through the Darien Gap to the vicinity of the town of El Real for the purpose of studying environmental problems affecting transportation support in military operations.

The main body of the group consisting of 3 officers and 33 enlisted men, departed Fort Eustis in increments on the 25th of July, and on the 1st and 3rd of August. The air section, consisting of 6 officers and 7 enlisted men, flew one U1A Otter fixed-wing aircraft and two H34 helicopters from Fort Eustis to Panama. After initial long-range reconnaissance, the Otter aircraft returned to Fort Eustis. The two H34 helicopters are supporting the operation.

During the preoperation phase in the Canal Zone, all personnel attended the Jungle Warfare Training Center's course in jungle operations and living, the course being a prerequisite to any jungle operation.

Much time was spent in checking out every item of equipment, since a spare part could mean the difference between a long delay in the field and a timely operation.

The operations "kicked off" early on the morning of 21 August with the following equipment:

- 1 Truck, Utility, 1/4-Ton, M38, with oversize tires
- 1 Jeep, CJ5, with Terra-Tires
- 1 Truck, Cargo, 2-1/2-Ton, M211, with a Jungletrac on the rear and Terra-Tires on front.
- 1 Truck, Cargo, 2-1/2-Ton, M211, with desert tires on front and rear.

1	Tracked Carrier, Nodwell, 5-Ton, RN110
1	Cargo Carrier M-116
1	Truck, Cargo, 3/4-Ton, M37, with oversize tires
1	Personnel Carrier, Amphibious, M-113
1	Power Wagon, Dodge, 4x4, with Terra-Tires
1	Tropical Floater (DINAH) 1/4-Ton.
1	Terrain Dynamometer Vehicle (Terrapin)
1	Weasel, M29C.
3	Rolling Liquid Transporters, 1,000-gallon capacity each
1	Set Jungletracs

Special Equipment Being Tested

Jungle fatigues
Jungle boots
New Army fatigue caps
Plastic canteens
Plastic-type wrist watches
Jungle hammocks
New-type rations (TV dinner style)
Propane gas stoves

Participation by Other Services

Ordnance Corps	4
Corps of Engineers	2
Chemical Corps	2
Infantry	1
Quartermaster Corps	1
Armor Corps	2
Special Forces	2
U. S. Navy	1
Panamanian Army	3

Environmental operations of this type, whether they are conducted in the jungle, desert, or polar regions, provide the means to determine the best type of equipment available of military and/or civilian manufacture, for operations under extreme environmental conditions.

In past wars, nations have had time to build up and provide supplies, equipment, and man power to conduct combat operations. Countries possessing the resources and industrial might, ultimately won those conflicts. Time for building no longer exists. The capability to fight must be immediate. It is essential that our logistical forces keep pace

with the combatant forces. The flexibility and mobility so essential to the conduct of combat operations are equally essential to our logistical forces. Mobility and flexibility cannot be realized without the means to transport men and equipment. This means is one of the reasons for conducting operations in environmental areas, since we must continue to develop methods and systems to provide a logistical transport capability for the mass movement of troops and supplies in every environmental area of the world, whether it be jungle, desert, or polar.

As you have heard, the Transportation Board has recently revived its 5-year environmental program, which will include testing in extreme jungle, desert, and polar areas.

Daily positions and weekly reports are being received from Operation Swamp Fox, and the current status will be presented to the panel.

A complete final report on Swamp Fox will be published and distributed by the U. S. Army Transportation Board.

USATRECOM ENVIRONMENTAL ACTIVITIES

Lieutenant Colonel James F. Wright, Jr.

U. S. ARMY TRANSPORTATION RESEARCH COMMAND

Fort Eustis, Virginia

USATRECOM ENVIRONMENTAL ACTIVITIES

As you know, TRECOM is not only responsible for specialized environmental research within the Transportation Corps, but, together with the Transportation Board and other TC elements that operate in adverse environments, is a large consumer of environmental and geographic information, including that which emanates from the Army-wide environmental research program that is monitored by your Panel. We indeed appreciate the opportunity, therefore, to present a series of papers that present a cross section of TRECOM's environmental problems and efforts.

Now, I would like to resort briefly to some definitions in order to outline more clearly the picture of TRECOM's environmental activities.

From the basic D/A definition of Applied Environmental Research, which I know the Panel members are quite familiar with as being the collection, interpretation, and promulgation of data of the earth sciences, including geography, geology, and meteorology, there was developed at one time or another an "environmental definition" of world-wide military transportation as being a system of equipment, knowledge, and techniques that relays cargo through a series of distinct geographic environments to the user in the field. In this system, individual items of equipment are usually functionally limited to accomplishing either a transport or a transfer operation and can effectively negotiate only one or at best two distinctive media in the total water, rail, road, off-road, and air environment enroute to the user.

Although somewhat theoretical, these concepts serve to emphasize clearly that our success in developing an all-environments transport capability is largely dependent on how well we understand the various environments and on our applying all available knowledge in our equipment and operations developments.

Thus, TRECOM employs an environmental approach towards its projects and programs, which can be categorized under two headlines. First, there is a great deal of environmental engineering incorporated in equipment projects. This engineering involves the maximum utilization of available data on the external operating environment of equipment, and the concept, design, and testing of this equipment are closely related to the environment. Second, the environmental approach and the attainment of all-environments capabilities require that a nominal program of

specialized research in environmental and geographical subjects that peculiarly affect TC equipment and operations be undertaken. I will outline these subjects a little later on.

Considering in greater detail the element of environment engineering that is inherent in TRECOM's equipment projects, not only are such items as the Logistical Carriers, BARCs, LARCs, RLTs, tractor trains, and certain air equipment good illustrations of end-items designed to the environment, but likewise, I believe, the papers that follow mine will be found to be representative of the application of environmental data and engineering in the development and engineering test of TC equipment of many other types.

Thus:

1. The paper to be presented by Mr. McCourt on "Environmental Aspects of Army Aviation" will outline many problems incident to low-altitude flight, together with certain induced aero-environmental problems.

2. The papers by Messrs. Graham and Poteate will describe rather difficult problems arising from such diverse factors as atmospheric electricity and ground surface materials that are induced during the operation of VTOL and rotary-wing aircraft.

3. Both Messrs. Roma and Simon will describe research that TRECOM is undertaking on technical mobility subjects involving surface-vehicle and soil-vehicle relationships. Though carried out under a mobility rather than an environmental research heading, this work is closely related to environment.

4. Mr. Vichness' paper on the development of the TC's dehumidified cargo containers will illustrate an item designed to maintain a nondestructive internal humidity for cargo in storage and transit in the presence of extreme humid ambient conditions.

5. The paper by Mr. Fielding on the GEM in environmental operations is an abstract of what, we believe, is an excellent and comprehensive geographic-environmental analysis accomplished by Booz-Allen Applied Research, Inc., which established as a guideline for the development of the GEM concept, physical

characteristics and performance criteria that will insure maximum mobility within limitations of reasonable installed power.

Now, turning to the TC's needs to undertake limited research into certain specific environments and geographic subjects that concern transportation, it is of course obvious that the TC must depend on the output of the Army-wide environments program for the bulk of its information within the more basic disciplines of physical geography, geology, physiography, and weather and climate. Bearing in mind that the scope and quality of this information, and the responsiveness of the various technical services responsible for its collection, are all unsurpassed, the TC's requirements for environmental research evolve into more specialized areas of the following:

1. Analysis of basic environmental data for purposes of evolving information specific to TC needs.

2. Studies of the geographic aspects of transportation. (Such studies would be especially beneficial in the collation and analysis of geographic and environmental information. These data could be useful for world-wide transport planning and for more effective operations in remote areas where adverse climatic conditions or rough terrain may exist.)

3. Studies of aero-environmental problems, especially those affecting low-altitude operations.

To accomplish these goals, it should be borne in mind that our objective is to expand knowledge of those particulars of geography and environment that pertain specifically to TC equipment and to develop techniques and countermeasures to reconcile TC environmental problems.

One of USATRECOM's environmental research projects is "Transportation Environmental Research Studies". The only active task under this project is entitled "Transportation Theory and Prediction".

The objective of this basic research study, for which Northwestern University is paid $25,000 annually, is to develop new, generalized concepts and theories concerning the underlying general relationships of physical, economic, and population influences that determine the establishment, distribution, and growth of transportation, particularly in undeveloped areas. Generally speaking, it is hoped that this study will ultimately lead to improved criteria for military planning and

operations involving transportation.

Dr. Garrison's paper, which will be presented towards the end of the morning, outlines this study in an excellent fashion, and he will be available to answer any questions about the subject. It should be emphasized that Northwestern University has been, and for some time to come will be, primarily concerned with the expression of theories and concepts. Up to now there has been no attempt to introduce military aspects into this study, but this will be done in due course.

USATRECOM's second environmental research project, which is currently in the process of being established, is entitled "TC Arctic Environments Research". The broad objective of this project is to acquire understanding of geographic, climatic, and mobility factors in Alaska and the adjacent arctic regions. This information is needed for support to develop the off-road operating capabilities of TC in this area. The project will be implemented by a series of studies of Alaskan transportation geography, surface and low-altitude air environments, mobility factors, and climatic stresses that are significant to TC. The U. S. Army Transportation Board (T-Board), who are operating the Logistical Carrier in Alaska, will be utilized for support of field research parties. The three tasks under this project, which are to be funded at an annual rate of $50,000 beginning in FY 1962, are as follows:

Task 1 - Transportation Route Geography Alaska.

This task will provide background transportation studies and geographic field research by utilizing air and light surface vehicles to locate and test a projected network of off-road access routes from the Fairbanks area to the Bering and Arctic Ocean coast installations.

Mr. J. W. Noble, who will present a report and movie film on Alaskan off-road operations at the end of this morning's session, has assisted USATRECOM in developing a preliminary "off-road" map of Alaska. This map can be utilized, after further testing, by crews operating the Logistical Carrier Train or the tractor-sled equipment for resupplying U. S. Air Force and Army installations in remote areas of Alaska. Mr. Noble will display the off-road map during his presentation. The off-road routes may be gradually upgraded and integrated into the future road net of Alaska.

Task 2 - Environmental Research of TC Arctic Mobility Tests.

This task will provide needed terrain data and environmental and mobility coverage for tests of the Logistical Carrier Train and other vehicles in support of the previous task.

Task 3 - Transportation Arctic Environmental Engineering Studies.

This task will provide coverage of climatic tests of TC air and miscellaneous surface items during the course of tests conducted by the Arctic Test Board.

Our third environmental research project, which has been established as a result of recent action by the Office, Chief of Research and Development to accelerate tropic research, is entitled "Transportation Environmental Research, Tropics". This project provides for the development of knowledge of the complex of geographic, environmental, and mobility factors that exists in tropical rain forest or grassland areas of the equatorial zone. These factors determine the character, performance, and mobility of military transport systems and of transportation equipment. This project will be implemented through a series of tasks that provide for research studies and field surveys and observations, to include liaison with industry in the tropics and participation in both T-Board and private expeditions. Subtasks will deal with such subjects as transportation routes and systems geography of tropic regions, surface environment and mobility factors affecting off-road movement, and tropic low altitude aero-environmental factors. Research will be directed towards those factors that are significant and peculiar to the Transportation Corps; all studies and surveys will be designed to provide a realistic profile of the conditions, problems, climatic stresses, equipment requirements, and transport systems and capacities that pertain to the tropics. Input from the Quartermaster, Engineer, and Ordnance Corps' environmental research programs will be utilized, tested, verified, and adapted to TC needs. USATRECOM will carry out all research aspects of this program. The project is expected to benefit greatly from both coordination with and through the field support furnished by the T-Board's environmental operations group; for example, the Swamp Fox party, which, as the Panel knows, has just completed an experimental operation in the Darien rain forest area of Panama. USATRECOM had three environmental observers and two equipment specialists with Swamp Fox, but they have not yet reported their findings.

The precise annual budget rate of USATRECOM's tropic research project has not yet been firmly established, although it is expected to be approximately $100,000 per year.

ENVIRONMENTAL ASPECTS OF ARMY AVIATION

E. V. Merritt

U. S. ARMY TRANSPORTATION RESEARCH COMMAND

Fort Eustis, Virginia

ENVIRONMENTAL ASPECTS OF ARMY AVIATION

INTRODUCTION

The environment in which Army aircraft operate is unique in many respects when compared with the normal concept of Aviation activities. Aircraft are generally considered as a means for transporting personnel and/or cargo between established geographical locations. Development of aircraft has been directed toward accomplishing this role in the most efficient manner and has resulted in aircraft that, for the sake of safety and efficiency, operate at relatively high altitudes and speeds. These aircraft, though highly efficient in the air, require elaborate ground facilities to support the flight operations.

The operations of Army aviation extend from that environment normally associated with aviation to one which is more in common with ground vehicles.

The predominant use of aircraft in the Army is for one purpose only--to assist the combat arms commander in accomplishing his mission. To do this, Army aviation must be fully integrated with those elements that can most profitably exploit the capabilities of Army aircraft. These elements include all of the combat arms and nearly all of the supporting technical services. As a tool of the ground commander, Army aviation must be so organized, equipped, and disposed as to be immediately responsive to the needs of the ground force. Experience has proven that an adequate degree of responsiveness cannot be achieved when the aviation element is widely separated, either geographically or commandwise, from the force with which it is working. Consequently, Army aviation is found where you find the Army; whether supporting tactical troops or technical service functions, Army aviation operates in the common environment of the Army.

SCOPE

This discussion will be concerned with two types of environment, which for the sake of convenience will be identified as "operational" and "induced". The operational environment will consider those elements and factors that influence, or have a bearing on, the overall efficiency and capability of Army aviation The induced environment is considered as the man-machine relationship and will cover briefly

some of the human engineering aspects apparent in this relationship. In discussing these areas and the problems associated with them, possible solutions being investigated will be described briefly.

OPERATIONAL ENVIRONMENT

Of major importance in the environment of an aviation unit in an operational area is the relative location of the aviation unit to that of the tactical unit to which it is assigned and also the nature of the base of operations itself. It should be remembered that the aviation unit moves from one area to another, as required, to provide immediate availability of aircraft to the tactical unit. For this reason and because of security considerations, it is not feasible to make major improvements to the area. Usually, any improvements consist only of pioneer work by the aviation unit where it is necessary to facilitate operations.

Bearing the foregoing in mind, let us now consider the major elements of the environment in which Army aviation operates and the overall effects that such factors impose on the aviation operation. Generally speaking, the effects can be classified in one of two general categories, namely, hazards and problems. For the purpose of clarification, hazards are identified as conditions that present physical danger, while problems are conditions that decrease the effectives or cause increased workload. Some of the effects, of course, fall in both categories, dependent on the degree of severity, duration of exposure, etc. For the purpose of this discussion, the major elements comprising the operational environment are identified, and the more common effects are discussed separately. It should be borne in mind, however, that interaction between two or more of the factors may very likely produce effects not covered here.

Climatic Conditions: The efficiency of aviation operations is often determined to a high degree by the climate in which the operations are conducted. The effects of climate range from requirements for increased support equipment to reduced payload capabilities of the aircraft itself.

1. Arctic Operations. Operations in the arctic impose added burdens during actual flight and in aircraft support functions. Such problems as "whiteout", difficult navigation, and blowing snow during take off and landing are some of the areas requiring attention. An entirely satisfactory means of maintaining aircraft in a state of readiness is not available.

2. Hot-Weather Operations: Problems associated with aviation operations in extremely high temperatures are primarily those of increased maintenance and reduced lift capability, in addition, there are flight hazards as a result of the high-density altitudes usually prevailing. The maintenance and logistical effort is increased because of the higher power requirements, which result in reduced service life of components of the aircraft. Lengthy exposure to high temperatures also results in higher rates of deterioration of many materials than is normal in temperate climates. Flight hazards are increased as a result of smaller margins between normal and maximum performance, which leaves little room on the part of the pilot for errors in judgment and techniques.

Terrain: Generally, the more difficult the terrain over which combat operations are being conducted, the greater is the need for aviation. Conversely, the terrain may play an important part in the effectiveness of the aviation effort. Effects of terrain include the following:

1. Location of aviation elements in relation to ground force.

2. Capability for air observation.

3. Increased flight hazards.

4. Increased maintenance efforts due to higher altitudes and inadequate operational sites.

In addition to the above, certain types of terrain impose additional problems and hazards. Operations in desert or other barren terrain increase maintenance requirements because of the abrasive action of the sand and dust in contact with bearing surfaces. Additional flight hazards are introduced as a result of blowing sand and dust during take-off and landing. This problem is particularly acute as it concerns rotary-wing aircraft, and the problem promises to increase with the advent of the new generation of VTOL/STOL aircraft, which have much higher disc loadings. Work is being directed toward finding a solution, but no really adequate and feasible means of relieving the downwash problem is in sight at this time. An additional problem continually encountered in aviation operations is the total inadequacy of certain ground support equipment in negotiating the terrain in which the aircraft is located. Much of this equipment performs admirably on a concrete ramp but is next to worthless in the normal environment of Army aviation. Little good can be accomplished by

having aircraft that can operate from practically any terrain but cannot be supported because of the inadequate mobility of the support equipment. Some effort is being made to improve this situation, and it is hoped that this problem will be relieved through the design of more suitable equipment.

OPERATIONAL HAZARDS AND PROBLEMS

The majority of Army aviation operations are conducted in close proximity to the surface of the earth. The concept of "nap-of-the-earth" operations has been necessitated by the rapid advances in electronic detection equipment and seeker-type weapons, which, it is felt by many, will deny operations at higher altitudes, especially in the forward areas. This concept, though decreasing the vulnerability to detection and possible attack, has introduced a host of hazards not usually associated with flight operations. If it is conceded that the concept is valid and will prevail, then the hazards inherent in this type of flying should be closely examined, and means of alleviating them insofar as possible should be determined. Normally, most air craft operations are conducted at sufficiently high altitudes to eliminate the possibility of collision with the terrain and objects on the ground. Altitude also provides a cushion, or margin for error on the part of the pilot, and increased chances of survival in the event of forced landing because of malfunction or damage to the aircraft. The current concept of nap-of-the-earth flying removes this cushion, and in so doing, presents numerous new hazards and problems. It should be noted that the hazards encountered will depend to a great extent on the type of mission being conducted, and it is emphasized that these shown are meant to be representative of typical missions.

Typical Hazards. Some of the hazards frequently encountered include the following:

1. Possibility of collision with terrain, trees, wires, and other obstacles along the flight path because of reduced visibility and insufficient reaction time of the pilot and aircraft.

2. Landing and take-off from confined areas under conditions of reduced visibility.

3. Collision between one aircraft and another because of reduced visibility and congestion in operating areas.

All of the above hazards are increased during night operations and during periods of marginal weather. In order to alleviate these hazards, we need in the aircraft improved instrumentation that will indicate the proximity of obstacles. We need improved methods of ascertaining and indicating the altitude and the speed of VTOL/STOL aircraft. This problem is expected to become more acute with the advent of new aircraft that have both VTOL and conventional flight capabilities with a transition flight regime. At the present time, we are using instrumentation in rotary-wing aircraft that was designed 15 to 20 years ago for fixed-wing aircraft. Needless to say, it is not the optimum. In many instances, the full capability of the aircraft is not utilized because of the safety margins that have been added to make up for the lack of accurate information regarding the flight condition. On the other hand, the aircraft capability is often exceeded, and an accident or other damage results because of the lack of such information. At the present time, some work is being done to find better instrumentation, but more effort is required to insure maximum capability of current and future Army aircraft, especially the latter.

Enemy Fire Against Army Aircraft. This is an additional hazard that requires attention. Heretofore, Army aircraft have enjoyed comparative immunity from enemy fire because of the nature of the aviation mission, which was primarily that of observation and of directing artillery fire. An effective deterrent in most cases was the ability of the crew to direct fire against positions from which the enemy was firing at the aircraft. However, with the introduction of helicopter-borne forces, armed reconnaissance, and other aggressive-type uses, Army aircraft present a lucrative target for nearly all weapons. Recent research effort has established means of providing a reasonably high degree of protection for the aircraft crews from small arms fire at acceptable penalties in weight and aircraft performance. This protective system is ready for development and can be made available at the request of the user. Further research is required to decrease the vulnerability of aircraft to electronic detecting devices and seeker-type weapons. This work is presently either in process or being planned.

Additional Effects Presenting Problems. In addition to the hazardous conditions surrounding Army aviation operations, as discussed above, there are other effects that, though not hazardous in themselves, present problems worthy of mention.

1. Because of the low altitude at which the aircraft fly, accurate navigation and reliable communication are difficult to achieve. So far as navigation in the forward area is concerned, we are still dependent on the pilot's map-reading ability. With all of

the other duties requiring his attention and with the distractions to which he is subjected, he must have considerable navigational ability in order to fly from Point A to Point B along circuitous routes while maintaining an altitude of only a few feet above the ground. It is surprising that the "disorientations" do not occur much more frequently.

2. Radio is of course the primary means of communication between aircraft and ground stations. Low-altitude operations reduce the ability to communicate effectively when the aircraft is any distance from the ground station because of terrain masking. This hampers operations in many ways and constitutes a serious problem in command and control of aviation operations. The majority of radio equipment in current aircraft was designed for operations over comparatively long distances, but under "line-of-sight" conditions. It is assumed to be within the realm of possibility that radio equipment could be provided with capabilities equal at least to that found in some taxicabs and service trucks. It is not known what effort is being expended toward relieving these problems, but the effects of the problems on the efficiency and capability of current and future Army aviation cannot be overlooked.

INDUCED ENVIRONMENT

The effects of the environment on the ability of the aviator to perform his mission adequately cannot be conveniently or accurately determined. It is difficult to ascertain how much and in what way a particular environmental factor will reduce the performance capability of the individual pilot. Consequently, an attempt will not be made here to assess the effect of specific items, or areas, which make up the environment of the pilot; rather, an attempt will be made to identify those areas which are known or suspected to contribute to the degradation of pilot performance. Prior to discussing the specific areas comprising the pilot's environment, the general conditions and responsibilities that surround the pilot and his mission should be established. These conditions will vary, dependent on the specific mission, type of aircraft, area of operation, local operating procedure, etc. Generally, however, it can be stated that the pilot is responsible for the proper conduct of the mission as it pertains to his aircraft and the crew. In many cases this may entail responsibility for a crew of 2 to 4 persons and as many as 20 to 30 passengers. The pilot in most cases will be responsible for ascertaining the

satisfactory mechanical condition of his assigned aircraft, preflight planning, selection of primary and alternate routes, loading and securing of cargo, briefing passengers on emergency procedures, and numerous other items prior to the flight. During the flight, the pilot is responsible for the safe operation of the aircraft, adherence to established operating procedures, and navigation and/or maintaining the proper position in relation to other aircraft. While performing these functions, the pilot is seated in an aircraft that is traveling at a speed of 60 to 100 knots at an altitude that may vary from a few to several thousand feet. The noise level may be in the vicinity of 80 to 100 decibels, with vibrations ranging from 3 to 80 cycles per second at various amplitudes. The pilot is required to monitor and adjust a half dozen or so controls in order to regulate the heading attitude, speed, and altitude of the aircraft. In addition, he continuously monitors the performance of the aircraft through interrogation and interpretation of a dozen or so instruments. While accomplishing this, the pilot is strapped in the seat and is further restrained from movement by a shoulder harness and communications wiring. The clothing of the crew is that which is normally issued to ground troops, with few exceptions, and is not compatible in many respects with the pilot's environment or functions.

Having thus established the general conditions under which the pilots of Army aircraft operate, let us examine some of the items that require improvement for greater safety, increased efficiency, and capability of aviation operations.

As stated earlier, most of the instrumentation used in rotary-wing aircraft was developed for fixed-wing application. The most serious of these shortcomings is the lack of suitable attitude and airspeed indicators. The indicators in use, though adequate for fixed-wing operation, do not have sufficient sensitivity or range for helicopter use. Some means of determining the speed of the aircraft relative to the ground is required, as well as a means of accurately indicating to the pilot the attitude of the aircraft. In addition, the current vertical speed indicators and altimeters do not permit the degree of precision required for many operations. Some work is being expended toward meeting the requirements for better instrumentation, but the effect that this equipment has on the success of future Army aircraft is such that greatly increased efforts are justified.

Some improvements in controls have been made in recent years, but much remains to be accomplished in this area to enhance the overall capability of Army aircraft. Essentially, controls should

be simplified and reduced in number. Control design incorporating fail-safe features that would alleviate the present catastrophic conditions resulting from control malfunction or damage should be considered. These features assume added significance in light of the hazards of weapons fire that may be directed against the aircraft during many of the missions envisioned under current concepts. The feasibility of reducing the number of controls required in rotary-wing aircraft is a subject worthy of serious study. The ability of the pilot to control the aircraft (rotary wing) without the use of all primary extremities is currently under study; however, no conclusions have been drawn at this time. It may be found that some type of armor protection for the pilot's extremities will be required as an interim measure, at least until more suitable controls are available on future aircraft.

Considerable work has been directed toward reducing the noise levels of many Army aircraft. However, at the present time the noise of several aircraft, especially rotary wing, is great enough to cause permanent damage to the hearing of persons exposed for prolonged periods. Stop-gap measures used to alleviate the problem have included the pilot's use of flight helmets, ear protectors and earplugs, and the soundproofing of the aircraft. These measures have been only partially successful, as can be attested to by the number of partially deaf helicopter pilots around today. We know much more about the noise problem and its effects than that of vibration. However, studies have indicated that the vibration problem may be as serious, if not more so, than that of noise. It is known, for instance, that certain amplitudes and frequencies of vibration cause detriments to visual acuity and the sense of balance, both of which could materially affect pilot performance. We need more information concerning the effects of vibration on the various senses and the corresponding detriment to performance. Such information, if available, could be used during design of new aircraft to eliminate those vibrations most harmful to pilot performance.

Cockpit lighting has been the subject of research, development, study, tests, and evaluations since the first aircraft was flown during the hours of darkness. Yet, it is a problem for which a satisfactory solution has not been found. The system currently in vogue consists of red lighting throughout the cockpit. This has been in style for a number of years, and nearly everyone is familiar with it. Familiarity, however, fails to relieve the system of its many deficiencies. Some of the most important ones are inability to read accurately the instrument range markings, difference in brightness

between various instruments, difficulty in distinguishing emergency lights from normal lighting, and difficulty in reading maps and charts. Apparently, there is no known solution to the problem, but it appears sufficiently urgent to justify a comprehensive study to at least determine if we are using the best available system.

SUMMARY

During this short discussion, we have described the environment of Army aviation, its peculiarities, and some of the problems associated with it. Some of these problems are new; some have been with us since the very early days of Army aviation. Some of them are common to all aviation activities, but many of them stem directly from the environment in which Army aircraft are employed. To assist in coping with this environment, we must have equipment that has been designed from the outset with the environment in mind. Equipment suitable for the normal concept of aviation will not fulfill our requirements. Our greatest needs appear to be in the areas of ground support equipment--not more equipment but equipment better suited to the job. Also required are better navigation and communications equipment; terrain and obstacle avoidance systems with better and more suitable instrumentation, especially for VTOL; simplified and fewer controls with fail-safe features where possible; and more rugged and durable aircraft capable of withstanding the rigors of field usage. Feasible solutions to these problems are being sought, but it is expected that many will be solved only through the evolution of equipment. In this respect, the foremost consideration in the design of new equipment for Army aviation is the environment in which it will operate.

VTOL DOWN-WASH IMPINGEMENT STUDY

R. R. Graham

U. S. ARMY TRANSPORTATION RESEARCH COMMAND

Fort Eustis, Virginia

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VTOL DOWN-WASH IMPINGEMENT STUDY

This paper treats primarily of the environment created or modified by the presence of VTOL aircraft operating near the ground. Research completed up to this point has been primarily directed toward defining the flow pattern from the down-wash as it strikes the ground and the effects of that flow on the ground and on objects in the flow pattern. Some investigations of possible corrective measures are now in progress.

Operational problems resulting from the down-wash from VTOL aircraft are as follows:

1. When the aircraft is operated over dust or dry sand, the down-wash causes a cloud of dust or sand that can obscure the vision of the pilot and ground crew, reveal the position of the aircraft to the enemy, cause excessive wear and damage to the engine and dynamic components, and cause damage to rotor and propeller blades.

2. When the aircraft is operated over gravel or clay, the down-wash forces rocks or clods to fly in all directions; as a result, injury may occur to ground crew, flight crew, and passengers, and damage may occur to aircraft, cargo, and nearby objects and buildings.

3. When the aircraft is operated over any type of terrain, the down-wash creates air velocities along the ground which, in some cases, exceed those with which ground personnel and ground based objects can cope.

Organizations involved in research in downwash impingement problems include U. S. Army Transportation Research Command (USATRECOM), Bureau of Weapons (BuWeps), U. S. Air Force Aeronautical Systems Division (ASD), National Aeronautical Research Institute (NARI), Corps of Engineers Waterways Experiment Station (WES), National Aeronautics & Space Administration (NASA), and various companies of the aircraft industry.

Research of particular interest to the Army has been conducted on various types of apparatus, including a 1-inch-diameter compressed air jet representing disk loadings up to 2,000 pounds per square foot (NASA); a 1-foot-diameter compressed air jet representing disk loadings

up to 100 pounds per square foot (NARI), a 2-foot ducted propeller capable of achieving disk loadings up to 150 pounds per square foot (Hiller Aircraft Corporation and WES); and a 15-foot propeller capable of operating at disk loadings up to 68 pounds per square foot (Kellett Aircraft Corporation). The devices were operated over smooth surfaces so as to define the flow pattern and over various soil types to determine the erosion characteristics of the soil when subjected to the down-wash.

Tests over smooth surfaces have produced results such as those shown in Figure 1. These dynamic-pressure profiles were obtained in the flow field from the 2-foot ducted propeller. It can be seen that operating the thrust-producing device within one diameter above the ground will produce dynamic pressures along the ground at one diameter from the centerline that are equal to or greater than the average of those normally produced at the exit of the device.

Increasing the operating heights of the device decreases the dynamic pressures along the ground. The variation of maximum dynamic pressure with distance measured from the centerline is shown in Figure 2 for various heights above the ground. It can be seen that the dynamic pressure at a location four diameters from the centerline has decreased to about 10 percent of the average at the exit of the device.

The thrust device was operated over various types of surface with the following results:

1. A cloud that would obscure the vision of flight and ground crews was created when operations were conducted at disk loadings as low as 3 pounds per square foot over fine dry soil or sand (Figure 3).

2. A dangerous condition resulting from flying particles was created when the device was operated at disk loadings of 60 pounds per square foot or more over a gravel bed. Figure 4 gives an indication of the amount of gravel that was moved by operation of the device for 42 seconds.

3. A vapor cloud was created when the device was operated at disk loadings of 60 pounds per square foot or more at a height of 2-1/2 diameters over water (Figure 5).

4. No dangerous erosion occurred when the device was operated at disk loadings up to 1,000 pounds per square foot over well established grassy sod.

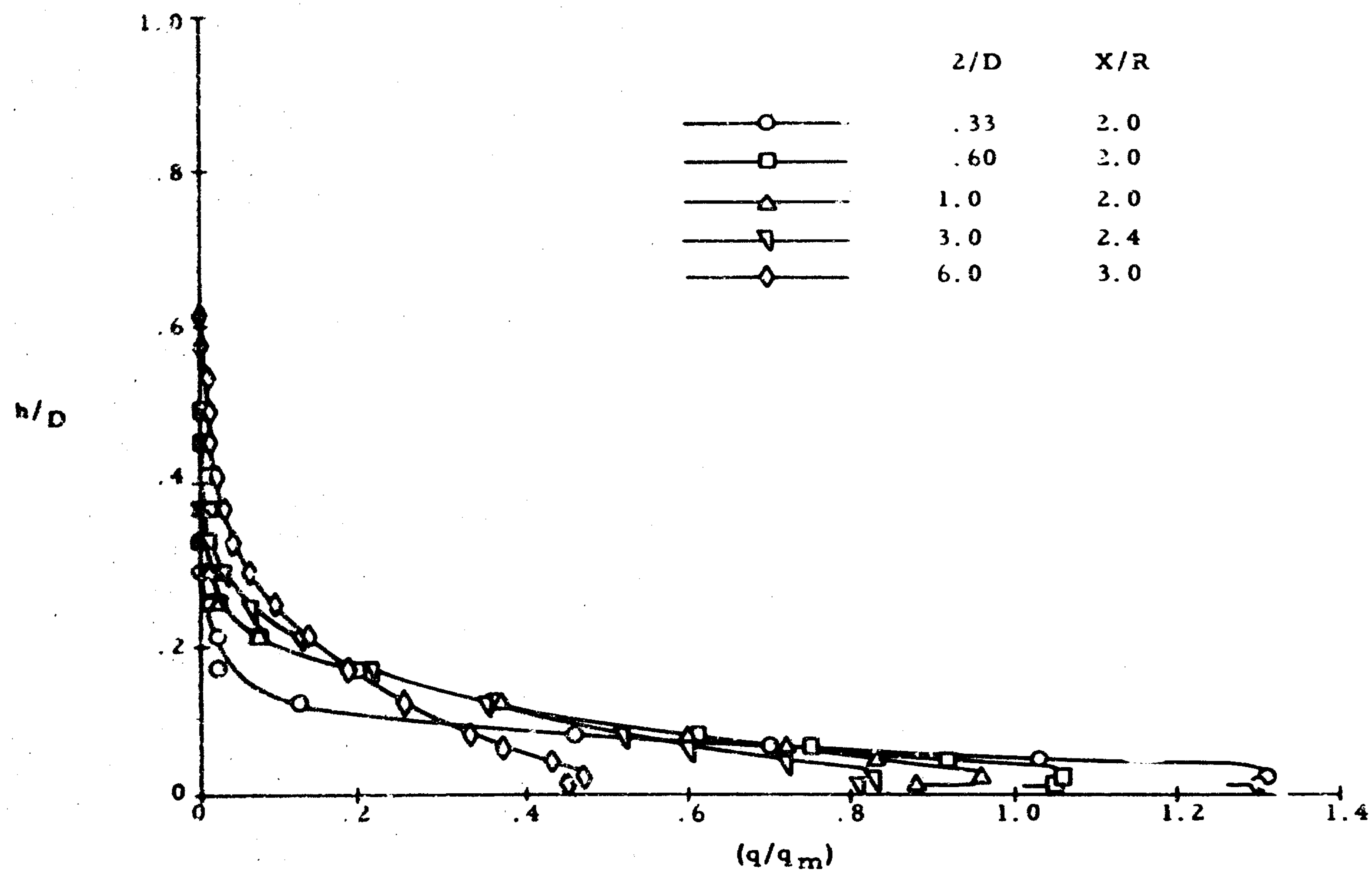

Figure 1. Typical Dynamic Head Profiles $\Theta = 0°$.

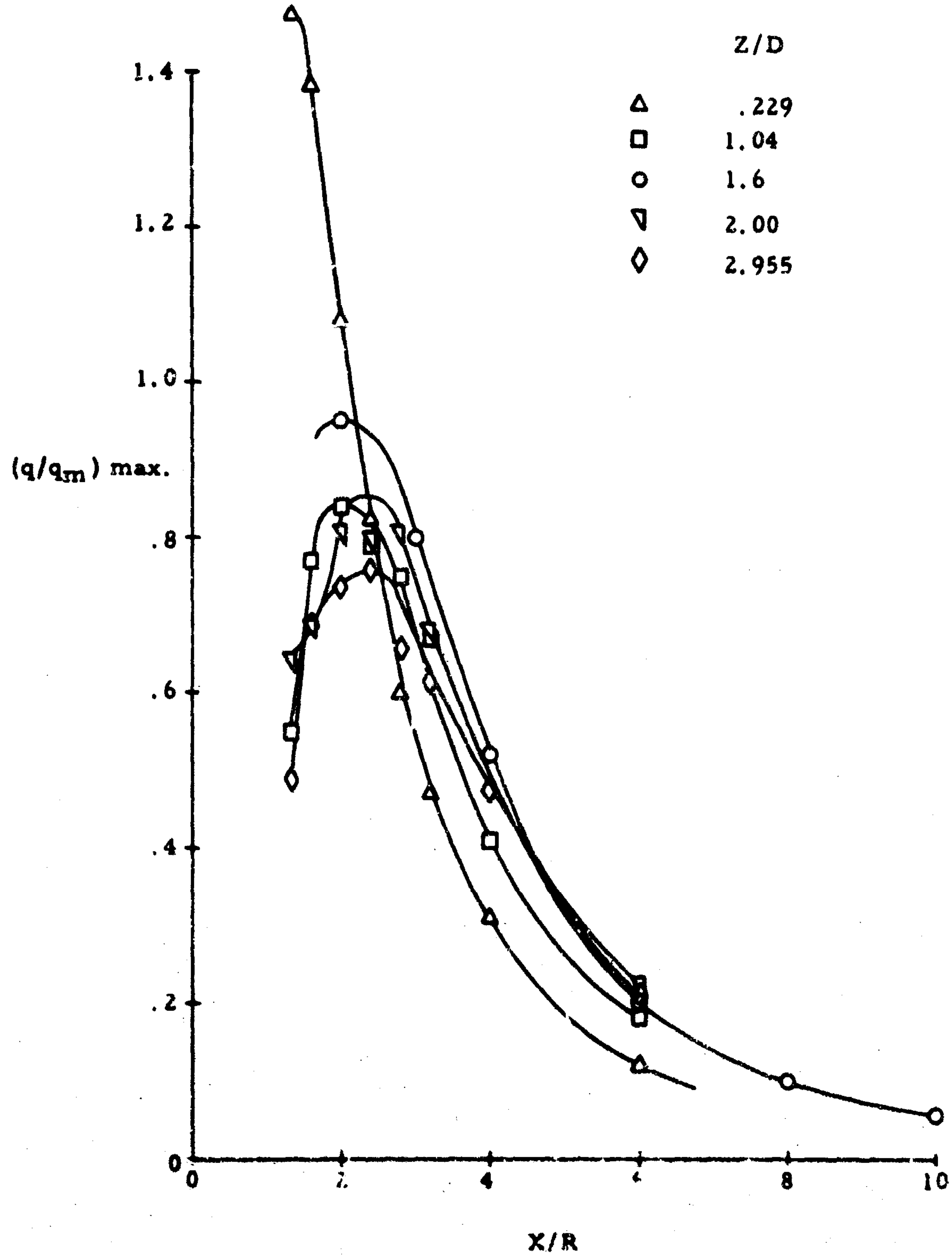

Figure 2. Variation of (q/q_m) Maximum With X/R
2.0-FT. Diameter Duct $\Theta = 0°$.

Figure 3. Test III-A108 During Operation.

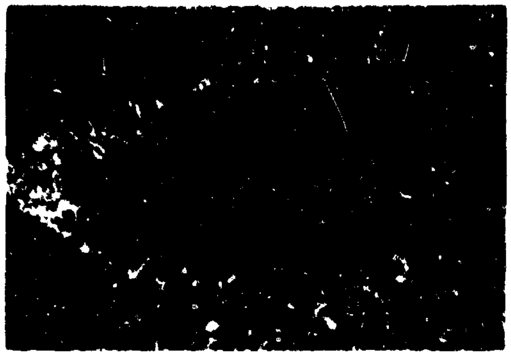

Figure 4. Test IV-A63 After Completion.

Figure 5. Operation at 60 Pounds per Square Foot.

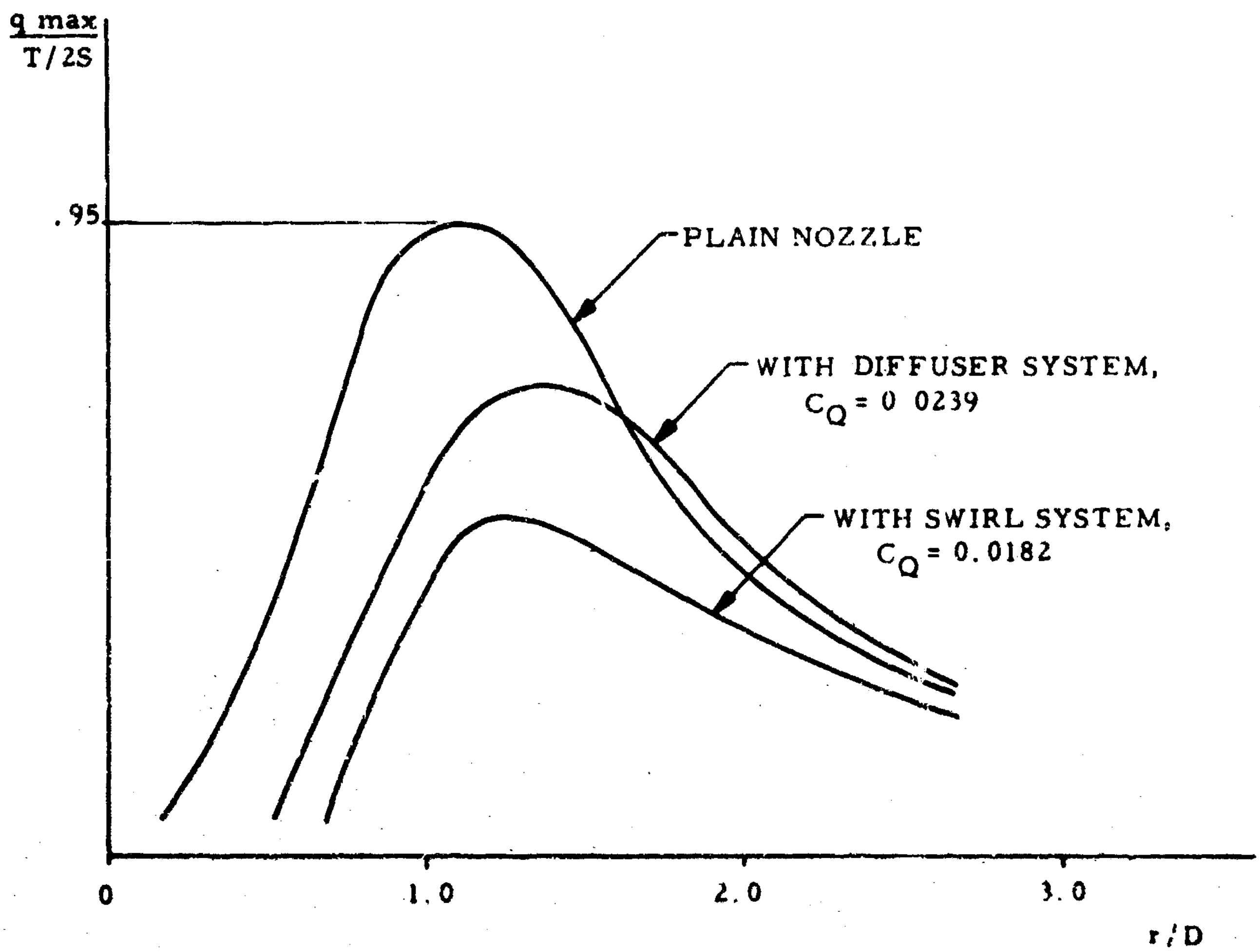

Figure 6. Variation of Maximum Ground Dynamic Pressure With Nozzle Configuration. ($h/D = 1.5$)

Research conducted on the 1-foot-diameter jet by a European contractor indicated that the placing of vanes in the exit of the thrust device would modify the flow field along the ground and might offer a means of relieving the adverse conditions to some extent. The final data are not yet available but preliminary data are shown in Figure 6. Absolute values are not shown, but it can be seen that when the device was operated at 1-1/2 diameters above the surface, a system of concentric circular diffuser vanes reduced the dynamic pressure along the ground about 30 percent and a system of radial swirl vanes brought about a reduction of almost 50 percent.

At the present time, work is continuing with the 1-foot jet in an effort to obtain further improvements in the ground flow conditions. Work is also continuing under a Navy-funded program with Keilett Aircraft Corporation to investigate the effectiveness of variations in airframe geometry and fuselage and wing flaps in altering the flow and preventing recirculation of ground particles and debris as a means of alleviating the downwash problems. Plans are being made to develop an analytical method of predicting the ground flow pattern from rotors and jets so that means of alleviating the problems can be investigated analytically, and adverse conditions can be avoided in the early stages of VTOL aircraft design and development. Plans are also being made to investigate the minimum sizes and shapes of lightweight ground covers or mats that offer the possibility of preventing ground erosion and recirculation of ground particles.

:TATIC ELECTRICITY

S. Blair Poteate, .'r.

U. S. ARMY TRANSPORTATION RESEARCH COMMAND

Fort Eustis, Virginia

L

STATIC ELECTRICITY

The problem of static electricity accumulation on helicopters has been serious ever since the Army first used these machines to transport cargo externally. The problem is divided into two major areas: the first is the possible injury to ground crew members performing the hookup; the second is the possible damage which may be suffered by the cargo itself during the sporadic discharge of high voltages. Although no serious accidents involving loads and static electricity have been recorded to date, the sudden discharge of thousands of volts of electricity through missile explosives and guidance components is of considerable concern to the Ordnance and Signal Corps.

The problem of injury to personnel has varied in severity from minor shocks to ground crewmen to a recent occurrence in Germany in which a man was rendered unconscious for a period of about 10 to 15 minutes by the sudden discharge of electrical energy from an H-34 aircraft. The Navy experiences a similar problem. When a pilot is being recovered from a ditched aircraft, the spark from the rescue hook may give the man in the water a sizeable jolt to add to his miseries, or, as in one reported case, the spark may ignite the fuel slick that is on the water. This has led to the procedure of dunking the hook outside the fuel slick and dragging it through the water to the downed pilot.

Let us consider for a minute what happens as a helicopter flies through the atmosphere. The air and the metal blades closely resemble the silk and glass rod we used to rub together in physics class to produce a static charge. When in contact, these two substances create a potential difference across their interface. During separation, however, if one of the substances is an insulator, the electrons cannot move along its surface with conductive freedom to discharge back into the other substance from which they originally came. In consequence, most of the electric charge will become entrapped on the two separating surfaces, especially if the separation is rapid. Hence, the two substances retain their characteristic polarities and charges from their contact electrification. Also, a helicopter may be charged through the release of ions in the engine exhaust gases. During the combustion process, ions are generated; and through their release in the exhaust gases, a net charge on the aircraft can be produced. A third method by which an aircraft can become charged in flight is by induction, which becomes effective when the craft is flying through high variations in the earth's electric field, as in flying under charged clouds. There are probably

other contributions to the charging of an aircraft, however, these three are felt to be the most significant. Unfortunately the results of these three methods of charging are not always constant. Obviously the earth's electrical field changes radically from day to day, which would result in extreme differences in the charge on the aircraft. The number of ions produced by the combustion of the fuel in the engine would be affected by the power being drawn from the engine, impurities in the fuel, and any number of other factors that probably could not be predicted accurately. We also know that changes in the atmospheric conditions very greatly affect the charge generation resulting from the rotor blades' turning through the atmosphere.

To date, we have only limited data that reflect the large effects of atmospheric differences on the voltage accumulation on a helicopter. We at USATRECOM now have a program under way that will measure the current that is generated and the voltage that is accumulated by all Army helicopters in several different atmospheres, to include clear air, dust-laden air, snow-laden air, rain, and mist. The results of this program will undoubtedly give a good indication of the exact magnitude of the problem. Our available data have been accumulated primarily at Edwards Air Force Base, California, which has a relatively clear, dry climate; the data are based on the performance of the H-21, H-34, H-37, and HU-1 aircraft. When these craft are hovering at 25 feet, 1,300 volts are accumulated on the H-21, 2,000 on the H-34, 1,100 on the HU-1, and 50,000 on the H-37. Several incidents have been reported recently in which an H-34 aircraft that was hovering for an external load pickup in snow-laden air discharged an arc of approximately 6 inches in length to the ground crew member. Using a breakdown gradient of approximately 20,000 volts per inch, which is a relatively conservative figure, would indicate that approximately 120,000 volts existed on the aircraft at that time. This figure, if compared with the 2,000 volts accumulated in clear, dry air, indicates a ratio of about 60:1 between snow-laden air and clear, dry air. If this factor were applied to the 50,000 volts accumulated on the H-37, approximately 3,000,000 volts would have accumulated during the snow operation. However, it is felt that 60:1 is too high a ratio and not appropriate in this case. Natural corona action would limit the voltage to a value significantly less than this.

Studies made by Auburn University have shown that even under ideal conditions an M-3 electrical squib can be detonated by a capacitor's discharging 1/2 joule of electrical energy through its leads. Now, what does 1/2 joule mean in terms of the voltage accumulated on a helicopter? The capacitance of the H-37 has been measured to be about 750 micromicrofarads at an altitude of 25 feet. The equation for

electrical energy in terms of volts and farads is $E = 1/2CV^2$. If an energy value of 0.5 joule and a capacitance of 750×10^{-12} farads are used, the equation can be solved and the voltage would be calculated to be about 36,000 volts. This shows us that the H-37, even in clear, dry air, stores enough energy to detonate an electrical squib. Obviously, with present-day munitions being what they are, a situation such as this is intolerable.

In 1959, USATRECOM initiated a project to find a solution to this problem. There were two possible approaches that could have been taken. First, we could have defined all the possible causes of static electricity generation and then attempted to find methods of preventing this buildup. Or, second, we could have accepted the fact that the helicopter is a fairly efficient generator of static electricity and then dissipated the accumulated charge when the helicopter was in the vicinity of the ground where the danger of an uncontrolled discharge would occur. The latter approach, which was considered to be the most profitable from a standpoint of time and money, was selected for the initial effort.

A number of avenues appeared to be possible in implementing the second approach. One was that of having passive wicks installed on the rotor tips, which would be similar to those used in fixed-wing aircraft to eliminate radio interference. The passive wicks appeared to do some good, but the voltage remaining on the aircraft was still too high from a safety standpoint. Use of the radioactive corona point was the second avenue investigated. From an analytical standpoint its use appeared to be satisfactory, but after testing, it was observed that too much radioactive material would be required to dissipate the current generated; also, ground personnel would be subjected to radiation hazards during normal operation, and in the event of a crash, the area might be contaminated. The third avenue, that of using high-voltage corona discharge, appeared to be the most feasible.

Under USATRECOM sponsorship, several research programs have been conducted on the application of the high-voltage corona discharge principle to the dissipation of static electricity generated by helicopters.

The phenomenon of corona discharge is one that has been known for years. If a body that is being charged with an electric potential has on its surface any sharp points, the electric field strength around these sharp points will be extremely high. As the voltage increases and reaches a certain level, which is determined by the shape of the point, atmospheric conditions, etc., the atmosphere surrounding the point will become ionized, a corona discharge will take place, and an actual

flow of current can be observed. The charge on this body will continue to increase until the current being discharged from the corona point is equal to the current being generated. This is basically the principle applied to static dischargers on fixed-wing aircraft. It can be seen, therefore, that a system of this sort would not be satisfactory for use with helicopters, since the steady-state voltage accumulated is usually quite high.

The corona discharge system described in this paper applies these same principles except that the discharge voltage has been boosted. To explain this, let us first assume that a helicopter in flight is accumulating a positive voltage. We will now take a high-voltage direct-current power supply and connect the ground side to the airframe and the positive side to a corona discharge point external to the aircraft, the external point being insulated from the aircraft frame. This, then, places the two voltages in series and results in an extremely high positive potential on the sharp point relative to the atmosphere. This high voltage on the sharp point produces the very high field strength necessary to ionize the atmosphere. Since the discharge probe is at a high positive potential, the negative ions in the atmosphere are strongly attracted to it and are propelled through the power supply to the airframe, where they will combine on a one-for-one basis with the positive particles in existence on the airframe and, if enough negative ions are generated in the atmosphere, reduce the net charge on the aircraft to zero.

Our research efforts have resulted in two breadboard corona discharge systems that will satisfactorily dissipate the static charge accumulated by a helicopter in flight. The first of these systems uses a rotating-vane field sensor and locates the high-voltage probe on the fuselage. As a result, the air velocity across the corona point is less than 150 feet per second. This allows approximately 7 microamperes to be discharged by a 20-kilovolt power supply. This system is rather large and bulky, and it is not certain at this time if 7 microamperes can furnish sufficient discharge current to "zero" an aircraft under all conditions. Flight tests of this system have been conducted and the system works well in the atmospheres encountered. The other system is being flight tested at this time on an H-37 at Edwards Air Force Base. This system makes use of the higher air velocities across the blades. The high voltage and the sensing probes are located at a point about two-thirds the distance of the blade's radius, where the air velocities are from 400 to 500 feet per second. A unique method of sensing is employed, which results in a large reduction in weight and complexity. As a result of the high air velocity across the probes,

the sensing mechanism is very sensitive, and the 20-kilovolt power supply is able to discharge approximately 35 microamperes. Preliminary data from the flight tests look very encouraging. This system weighs about 5 pounds; the first system described weighs 45 pounds.

As stated earlier, we have given much thought to the idea of eliminating static electricity at its source. Although it is entirely possible to match dielectrics and eliminate any charge generation in a given environment, even a slight change in temperature, humidity, contamination, etc., of the atmosphere or of the blade surfaces would change the dielectric constants, and a voltage would be generated. Therefore, we believe that the problem is here to stay and that our only course is to provide better means of dissipation. We are looking at newer isotopes, other electronic systems, and generally at anything that will produce ionization. Of course, what we want is a piece of equipment which has no moving parts, nothing to wear out or malfunction, costs nothing, weighs nothing, occupies no space and requires no power or maintenance. I don't think we'll find it, but we're getting close.

SCALE MODEL TESTING OF TIRES IN SAND

Carlo J. Roma

U. S. ARMY TRANSPORTATION RESEARCH COMMAND

Fort Eustis, Virginia

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SCALE MODEL TESTING OF TIRES IN SAND

INTRODUCTION

The history of the development of off-road wheeled vehicles clearly demonstrates that the most important single design consideration has been the proper selection of tires. For years, the development process consisted of adapting larger "off-road" tires to existing vehicle chassis intended only for on-road travel. This method allowed only modest gains because of the expensive and time-consuming modifications imposed by clearance difficulties and limitations imposed on the existing vehicle by power-train capability.

Without a technology that could predict the improved performance, many efforts were disappointing because too much in terms of improved performance was claimed for relatively modest modifications. The inherent limitations imposed by the current chassis then resulted in years of testing the off-road tires with varying secondary factors in the vain hope of producing dramatic improvements in the ground-traversing performance. Such factors included tread patterns, depth of grousers, low-profile versus round-profile cross sections, and single tires versus dual tires. These conditions led to reluctance by the users to accept compromises in body configurations that were less susceptible to efficient cargo handling for only marginal improvements.

BACKGROUND

A considerable amount of tire testing was conducted during World War II. The only effort that was specifically oriented toward providing a guide or index to proper selection of tires for off-road (sand) usage was the work done by Karl F. Eklund (Reference 2). This work was further refined by Richard C. Kerr in 1955 (Reference 6). A Mobility Index was formulated which provided the designer with a guide for use in selecting tires for off-road vehicles. The index was based primarily on tire tests in sand; the acceptable index, by being increased, could be expanded to include other types of terrain. For example, a 100-percent Mobility Index was considered to be acceptable for sand, however, a Mobility Index of greater than 100 percent would be necessary to be barely acceptable for other soils and

snow. This scheme did not receive widespread utilization for a number of reasons. First, it did not provide a quantitative performance guide; secondly, the Mobility Index assigned invariably meant different degrees of mobility for each type of terrain. However, it is useful to this day for mobility evaluation of tires, and will remain so until it is supplanted by more recent work.

Efforts have been made to study and analyze all previous test work on tires in the hope of determining the essential factors that dictate off-road performance (References 5 and 12). These efforts have resulted in some interesting relationships but have failed to provide a design guide.

Comparative evaluation of full-size vehicles was the only guide that designers found to be acceptable. This was expensive and required excessive time to arrive at a design decision (References 3, 4, and 9).

PAST APPROACHES TO THE PROBLEM

A number of approaches have been tried to avoid the necessity of testing full-size wheeled vehicles.

Single-Tire Test Apparatus

The use of a single-tire test apparatus had the potential that testing single tires on repeated passes would simulate testing 4x4 and 6x6 vehicles (References 1 and 13). Further, it was reasoned that tests with single tires could be performed more quickly and cheaply than tests with complete vehicles. Unfortunately, this program never correlated the single-tire test results with those of vehicles. Further, the results did not provide guidance as to the expected performance of tires in scaled proportion to the tires actually tested. The approach proved to be less efficient than originally surmised because of the repeated tests required to simulate 4x4 and 6x6 vehicle configurations.

Laboratory Model Tests

A number of investigators in the United States and other countries have made mobility studies by testing small models in laboratory basins. Most investigators used sand because of its stability and reproducibility. This approach thus far has not produced usable design data because of the lack of correlation between laboratory results and the results obtained with full-size vehicles operating in natural terrains. This approach is also handicapped by the impossibility, for all practical purposes, of producing snow and other types of terrain in the laboratory. For many vehicles, it is essential that performance in a number of different types

of terrain be predicted and the final design decision based on acceptable performance in the most "critical" terrain.

Theoretical Studies

Theoretical studies were usually based on mathematical equations used in soil mechanics and expanded for application to vehicular performance. These studies usually were coupled with attempts to verify the theory by scale-model tests in laboratory basins. Unfortunately, this approach was handicapped by a meager knowledge of the fundamental parameters involved in vehicular performance as well as by the shortcomings of the laboratory test approach in general. Since the early investigators considered the pneumatic tire as essentially a solid, rigid wheel, most laboratory work was conducted with rigid wheels. This basic assumption was sufficient to make many designers skeptical of any results obtained or conclusions reached by using this approach.

TRANSPORTATION CORPS APPROACH TO THE PROBLEM

The U. S. Army Transportation Research Command has been desirous of developing a research guide to the selection of tires for off-road vehicle performance. The approach selected had to meet the following requirements:

1. It had to produce data that could not be disputed.
2. It had to have the potential of producing results as quickly as possible.
3. The data had to be usable as a design guide to predict performance of off-road wheeled vehicles.

Therefore, it was decided that a field model test in natural terrains and using modest scale ratios (about 1/4) together with direct correlation between the model and full-size vehicles would be the approach most conducive to the needs of the U. S. Army Transportation Research Command.

The first attempt at correlation in sand was made with the Logistical Cargo Carrier (Figure 1). It was chosen because it was undergoing engineering tests at the time, and with its large 10-foot-diameter low-pressure tires and relatively low wheel loads, it represented a vehicle having a high degree of mobility. A 1/4 scale model of the

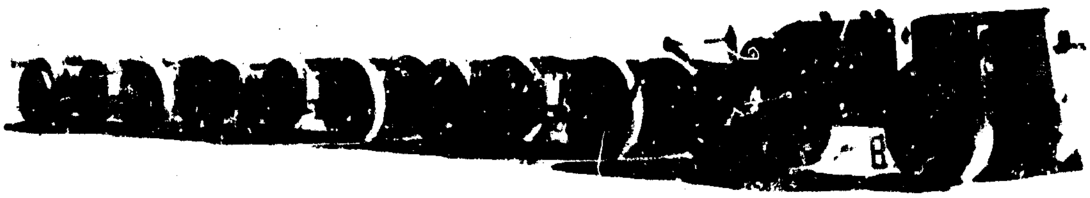
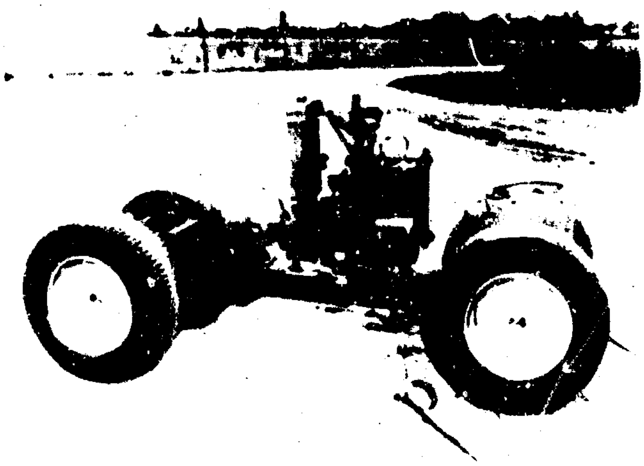


Figure 1. Full-Size Logistical Cargo Carrier.

lead unit was designed and constructed with preciseness in regard to all dimensions and to weight distribution. The model was instrumented so that torques at the wheels could be recorded in the event that wheel torques had to be scaled for accurate correlation. In spite of all this care as well as using special molds for the tires and special wheel patterns, the net cost of the model was a small fraction of the cost of the full-size vehicle (Figure 2).



The approach at first envisaged that the slightest variation of any significant factor would require a separate actual field test of the model.

Figure 2. 1/4 Scale Model of Logistical Cargo Carrier.

CURRENT STATUS OF THE TRANSPORTATION CORPS APPROACH

It has been demonstrated that drawbar pull and sinkage performance of the lead unit of the Logistical Cargo Carrier in sand can be correlated with that of the 1/4 scale model when both the full-size vehicle and the model are geometrically similar and model weight is appropriately scaled (Figure 3).

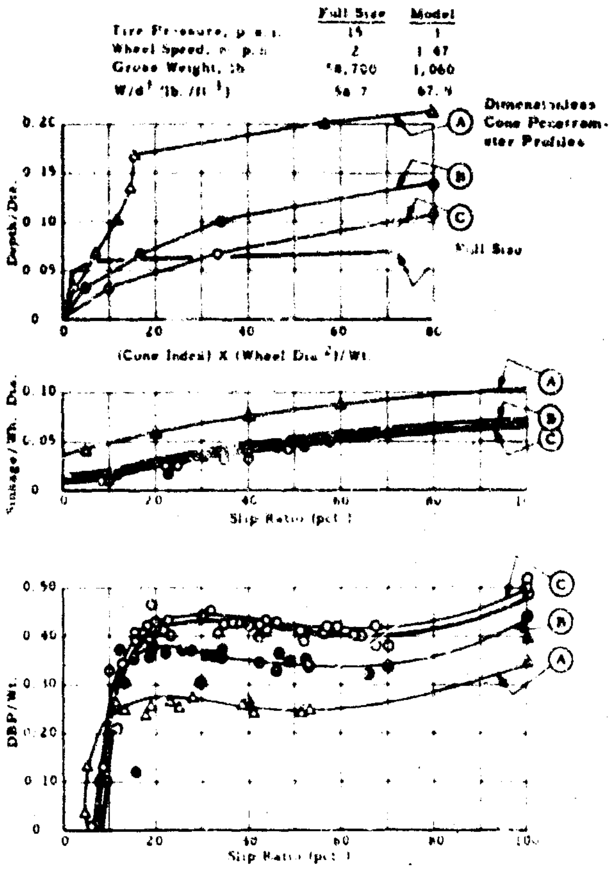


Figure 3. Correlation of 1/4 Scale Model With Full-Size Vehicle (Operating Without Grousers in Wet Sand).

The next vehicles used for correlation testing in sand were the Marsh Buggy and a 1/4 scale model of it (Figure 4). The Marsh Buggy was selected primarily because of its ideal characteristics for correlation tests in snow, marsh, and mud. However, it also represented extremely light wheel loads and served the purpose of demonstrating that correlation could be accomplished for such light wheel loads (Figure 5). It soon was realized that the performance data could be presented in a form whereby the influence of a large number of primary factors could be predicted without testing for each slight increment.

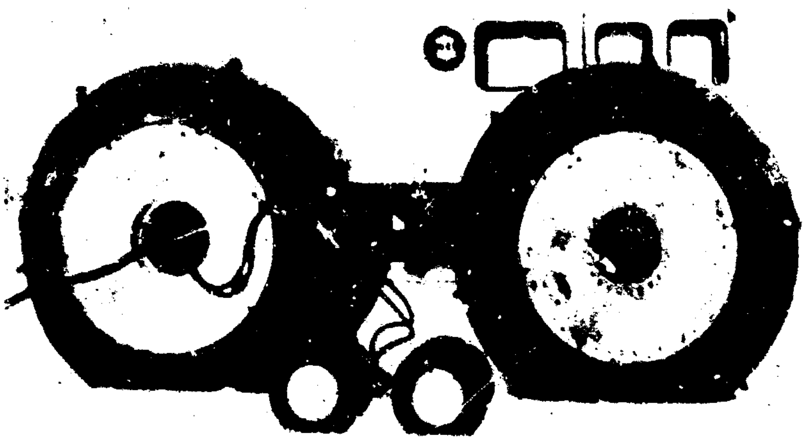


Figure 4. Marsh Buggy and 1/4 Scale Model.

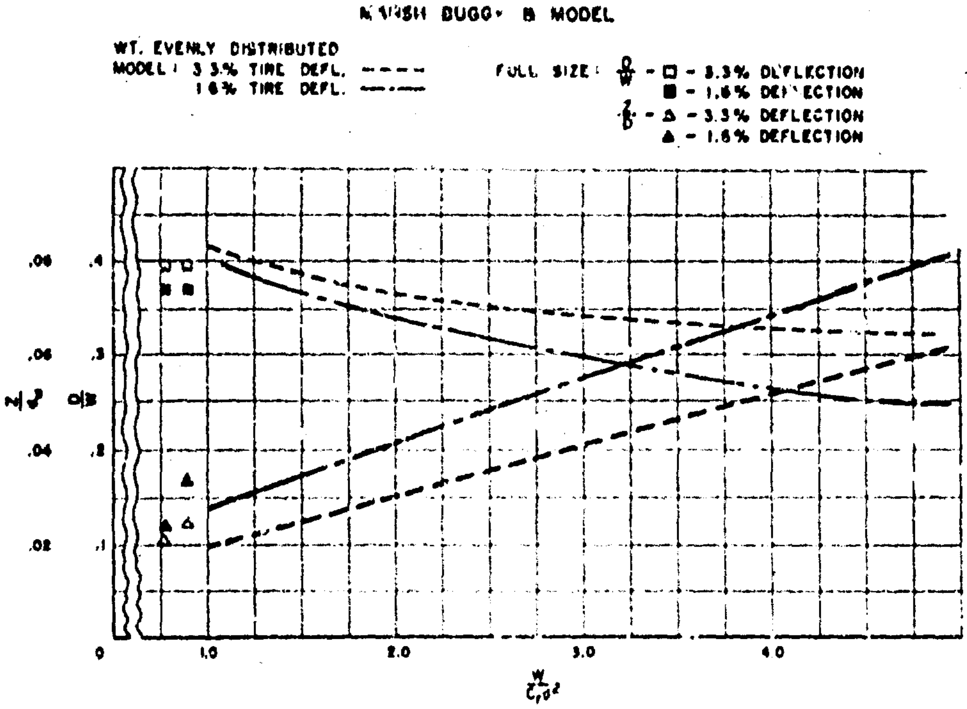


Figure 5. Drawbar Pull and Sinkage Correlation of Marsh Buggy and 1/4 Scale Model.

The next program consisted of tests of a group of tires of approximately the same overall diameter and with different diameter-to-width ratios (Figure 6). It was found that performance profiles for

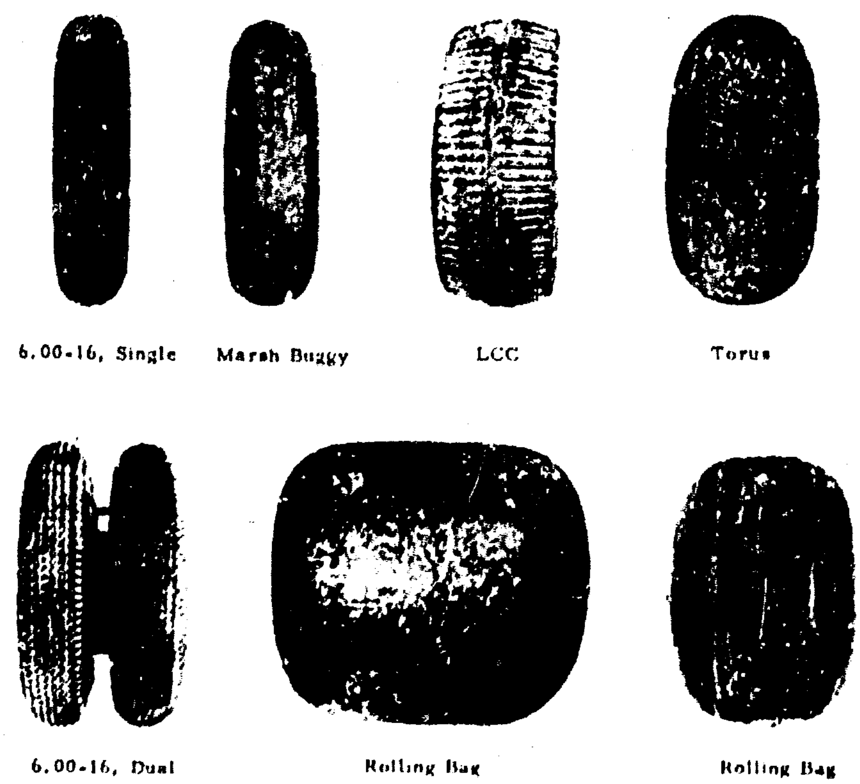


Figure 6. Series of Scale Model Tires Tested.

all tires could be presented for each percentage of deflection (Figure 7). In all cases, the data were restricted to a 4x4 configuration.

The most current program was concentrated on a verification of the fact that the performance profiles truly represented extreme ranges with respect to weight, sand strength, deflection, and tire diameter. The performance profile based on 30 percent deflection is of particular interest because it represents the practical deflection limit

		b/d	DEFLECT-pct O.D.	DEFLECT-pct S.H.
C	6.00-16, S	.23	5.5	30
X	MARSH BUGGY	.35	5.8	30
Δ	LCC	.40	6.1	30
□	TORUS	.49	10.0 & 7.6	24 & 18
◊	6.00-16, D	.52	5.6	30
O	36-22 BAG	.63	9.9	30
D	24-24 BAG	1.0	10.5	30

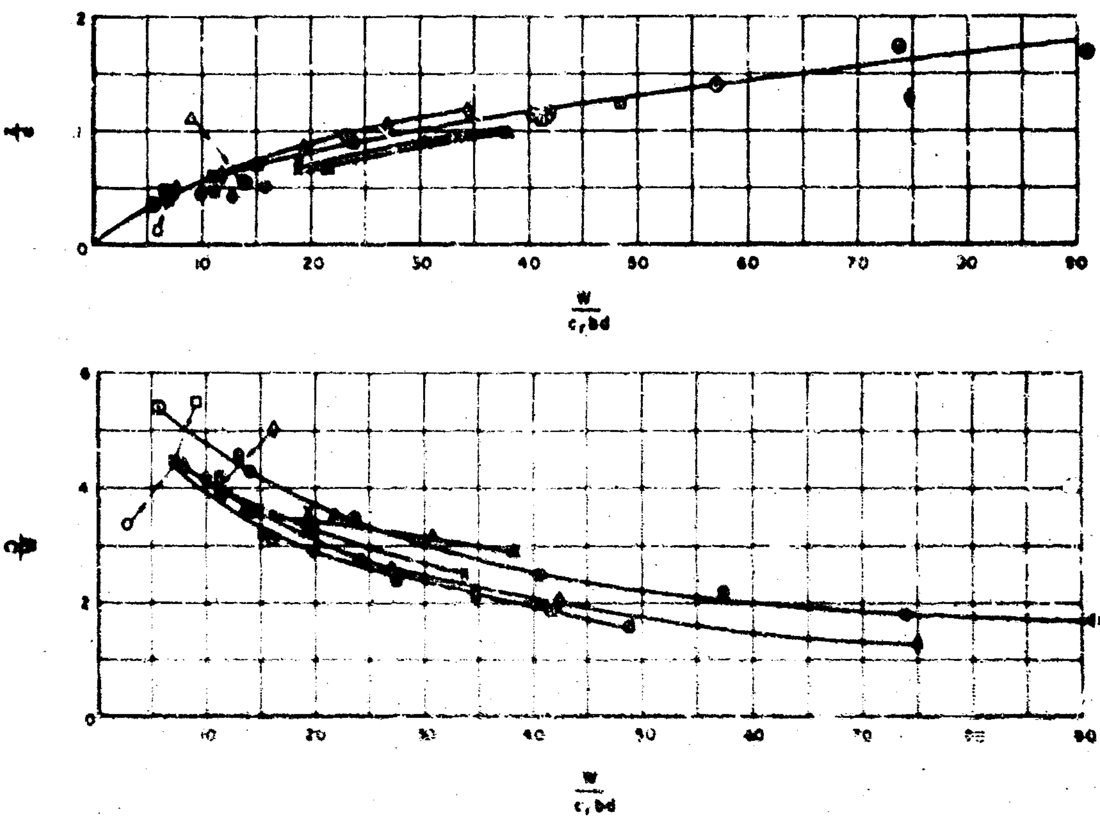


Figure 7. Performance Profiles of Tires in Sands.

permissible from a tire-life standpoint (Figure 8). However, the most general and most useful curve is Figure 9. This curve has collapsed data from 160 different tests. Weight was varied from 50 pounds per tire to 50,000 pounds per tire. Sand strength included both soft tilled sand and naturally compacted sand. Deflection varied from 1.5 percent to 30 percent of section height, and overall diameter varied from 25 inches to 120 inches. Recently developed wheeled vehicles such as the LARC, GOER, BARC, and Landing Craft Retriever (Figures 10, 11, and 12) were tested and their data collapsed into the curve with ± 10-percent error.

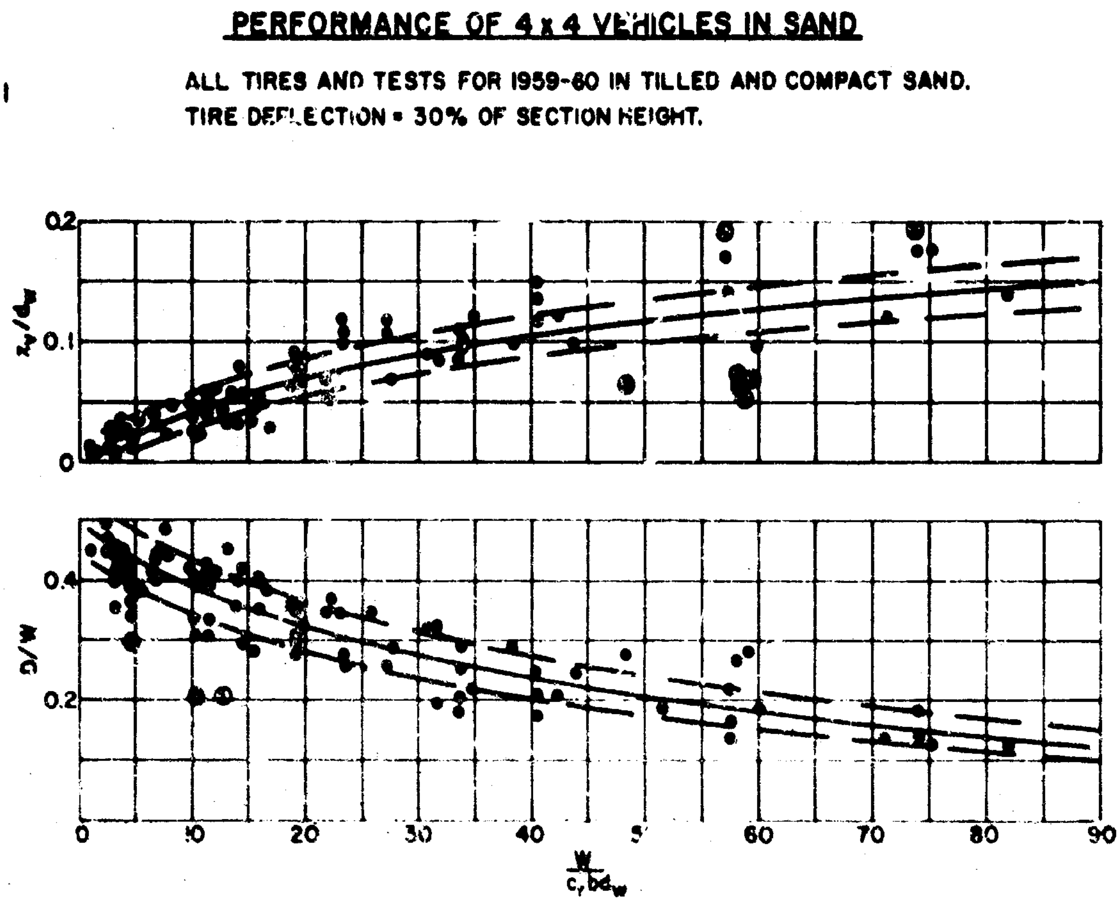


Figure 8. Thirty-Percent Performance Profile of All Tires.

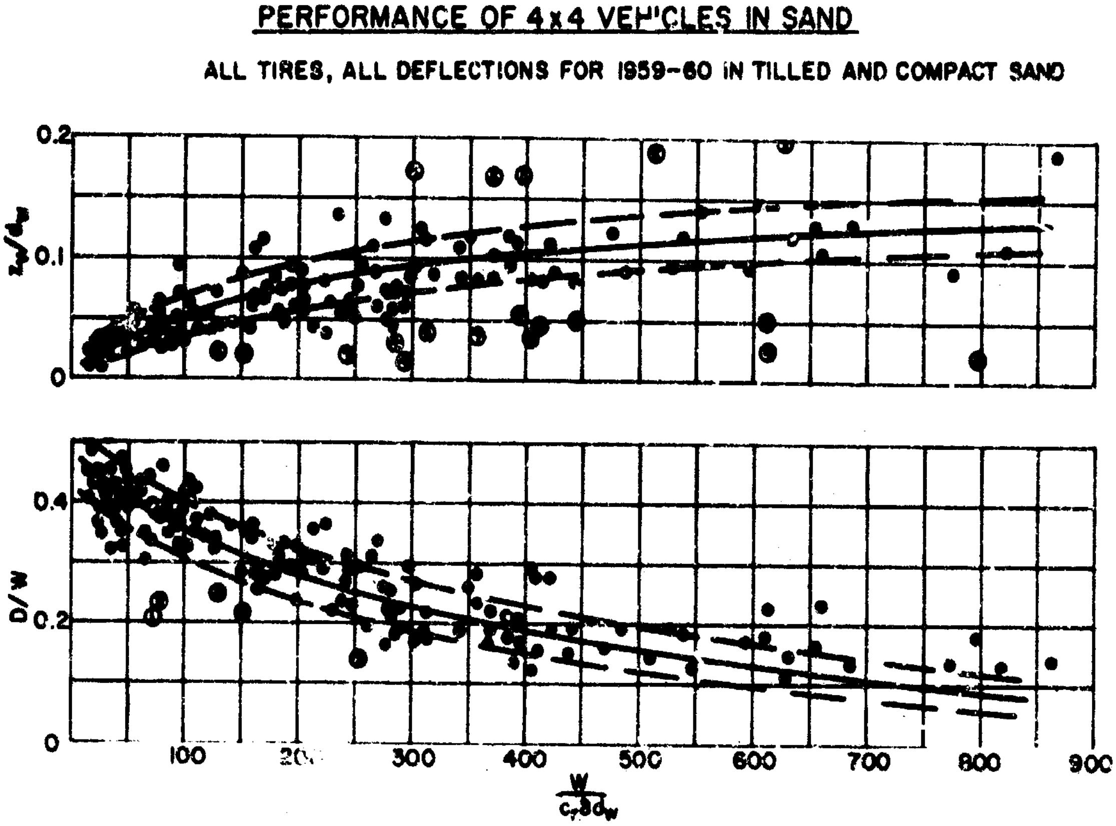


Figure 9. Curve on D/W Versus $\frac{W}{c_r \delta d_w}$.

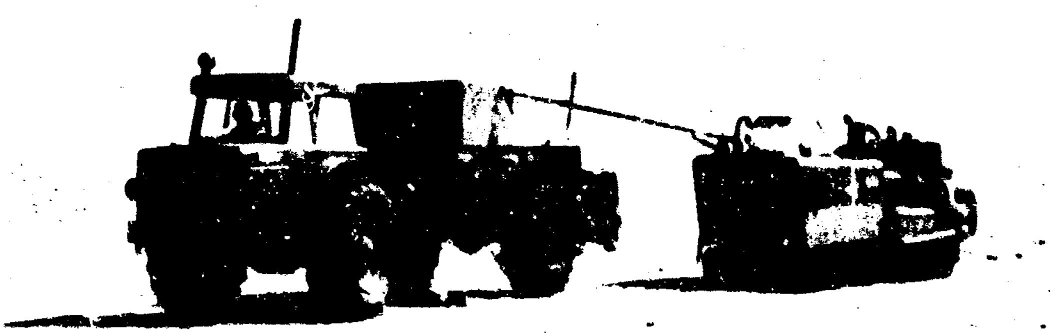


Figure 10. GOER.

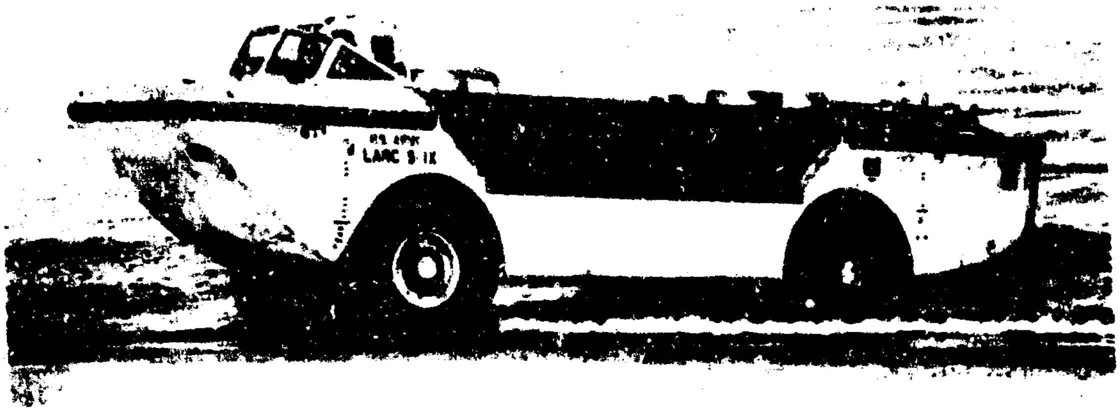


Figure 11. LARC.

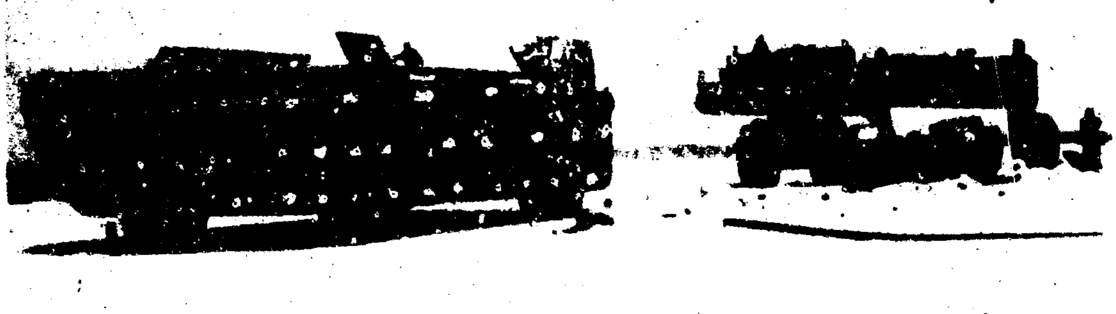


Figure 12. BARC and Landing Craft Retriever.

FUTURE PROGRAMS

Although Figure 9 is extremely useful for 4x4 vehicle configurations, it does not apply for 6x6, 8x8, or train configurations. A program is already underway to determine if the single-tire test data, References 1 and 13, can be correlated with the 4x4 data. If successful, the third-pass single-tire test data can be extrapolated to plot a performance profile for 6x6 wheeled vehicles similar to that in Figure 9. A few spot checks with actual 6x6 vehicles would verify the validity of the performance profile and would thereby negate the requirement for an extensive test program as was followed for the 4x4 configuration.

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GROUND PROFILE INSTRUMENTATION

Herman P. Simon

U. S. ARMY TRANSPORTATION RESEARCH COMMAND

Fort Eustis, Virginia

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MEASUREMENT OF THE CROSS-COUNTRY TERRAIN ENVIRONMENT

INTRODUCTION

The word "mobility" as now utilized by the military has many definitions, but for the vehicle designer it defines a difficult area and environment to cope with. This is the terrain in situ--not only roads, trails, or paths, but the ground as nature has conditioned it by erosion, vegetation, climate, etc. The ability to traverse cross-country terrain involves many considerations, one of the most important of which is rough ground performance, which is indicated by vehicle speed, human tolerance to vibration (low frequency, high amplitude), and limiting forces on cargo and equipment.

To provide adequate design criteria, methods must be developed and analyses must be made to predict performance. It is not the purpose of this paper to present a lengthy review of analytical studies of vehicle, human, and cargo dynamics. Several such reviews currently exist: Bekker, Bogdanoff and Kozin, Roach, Sattinger on vehicles (References 1, 2, 5, and 6); Horneck, Boettcher, and Simons on humans (Reference 3); and many others. These analyses in one form or another are dependent on the assumption of forces imposed on vehicle(s) traveling cross country. The validity of these assumptions and the utilization of the methodology developed can be attained only by an extensive collection of accurate information on the geometric characteristics of the terrain over which vehicles must operate.

This paper deals with the measurement of terrain profiles for the purpose of providing power spectral density distributions for use in related dynamic analysis. The need for this type of information is evidenced by the numerous reports lamenting the fact that so little work has been done in characterizing ground roughness statistically.

PROBLEM

The collection of profile data to characterize terrain quantitatively becomes a mammoth task unless some reasonable approach is taken to the delineation of topographical areas. In the past, the military has utilized the terms "desert", "arctic", "subarctic", "tropic",

"temperate", etc. Though these terms are too generalized for utilization, they can be used if a specific number of reoccurring land forms typify the area. For example, the Waterways Experiment Station of the Corps of Engineers in a recent study to determine test areas in the desert test station at Yuma, Arizona, that approximate world deserts, arrived at a proposed correlation method. If this approach is satisfactory, then the problem of gathering data becomes more reasonable.

To be all inclusive, data-gathering must also include the geometry of natural and man-made features, their occurrence, and their distribution. Vegetation, rocks, slopes, and ditches become important aspects in describing the terrain. Studies accomplishing this form of data-gathering are currently underway by all interested research laboratories of the U. S. Army.

To complete the picture, a record is required of the ground form, which is the elevation of each point along a route as a function of the horizontal distance along the route. Such a record then can be analyzed so that the amplitude of each sinusoidal component as a function of ground wavelength can be given in terms of spectral density.

The problem, therefore, consists of three parts: the delineation of geographical areas into a specific number of typical types; the determination of occurrence and distribution of natural and man-made terrain features; and the collection and analysis of ground wave form.

PROFILE INSTRUMENTATION

Mr. F. N. Hveem of the California Division of Highways has done an excellent job of reviewing profiling devices for recording pavement roughness (Reference 4). He has listed these devices in a number of classes, as follows:

1. Devices that plot a profile from level notes, or devices which utilize a similar reference plane.

2. Devices that measure deviations with a straight edge laid on the surface, in which the reference plane corresponds to the two highest spots within the length of the straight edge.

3. A mobile beam with a single wheel at either end and a center recording wheel free to move vertically.

4. Devices that record vertical oscillations of a wheel with reference to a suspended weight or mass (the U. S. Bureau of Public Roads built such a device utilizing the front axle of an automobile).

5. Devices in which the reference plane represents the mean of a number of points of contact with the road surface.

6. Devices that measure the slopes of the profile by measuring the angle generated by two wheels some distance apart with reference to a vertical plane (slope integration method).

All the devices utilize a continuously changing plane of reference, and some require a transposition of data into a useable form. It appears that a profile measuring system should be accurate, reliable, and mobile, and should have a data output that can be fed directly to a computer.

Investigation of various systems that have been tried indicated that a system developed by Wright Air Development Division for measuring airport runway roughness could be modified to provide the system required.

DESCRIPTION OF THE INSTRUMENT SYSTEM (Figures 1, 2, and 3)

The system consists of two parts: the collimator, which projects a highly collimated light beam toward the profilometer, and a profilometer that is equipped with a photoelectric sensor. As the profilometer moves, the sensor is held centered on the light beam by a servo system. A direct drive introduces the profile variations between the surface and sensor position into a useable output. Currently, a digital encoder is being installed on the profilometer that will facilitate the use of profile data directly on USATRECOM's data processing equipment. This will consist of a shaft position to digital encoder whose output is punched on a paper tape.

The system will be capable of measuring elevations at 6-inch intervals at speeds up to 5 miles per hour. The collimator includes a high-intensity light source and a collimating lens system which is capable of projecting a well-defined beam of light for approximately 2,500 feet under reasonable atmospheric conditions. This light source establishes a reference plane.

The profilometer consists of a wheel cam follower, which follows the terrain profile, and a photoelectric sensor, which is kept vertically centered on the light source by action of the servo system. The distance between the wheel and the sensor is thus a direct measure of the elevation of the profile with respect to the horizontal reference beam. At 6-inch intervals, a switch, driven by the profile wheel follower, causes data to be read out of the encoder into the digitizer and onto a paper tape.

Tests on runways have indicated that profile measurements made by the system were within ±0.2 inch of those made by rod and transit.

Although the current system has not been fully evaluated on cross-country terrain, there is every indication that it should perform satisfactorily. Time and additional work with the system will prove, or disprove, this statement.

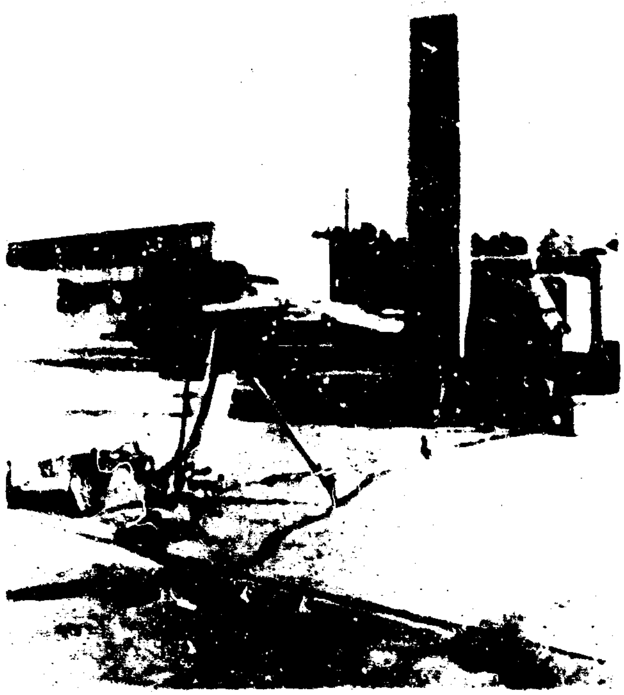

Figure 1. View Showing Profilometer in Normal Operating Position at Beginning of Test Run.

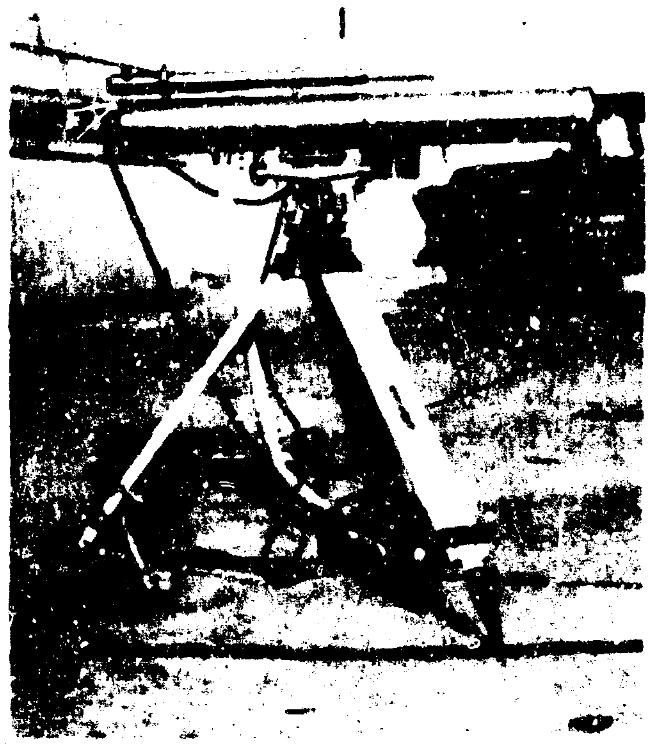

Figure 2. Collimated Light Source.

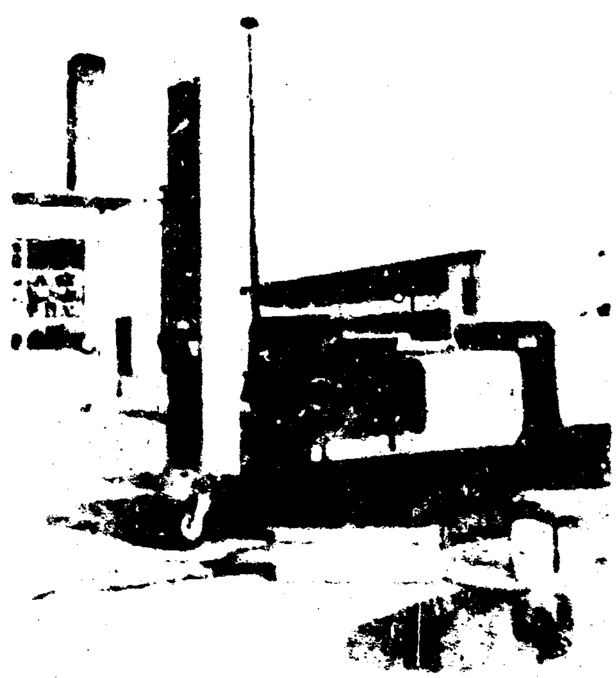

Figure 3. Optical Sensing Head Mounted on Polecat Vehicle.

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APPLICATION OF "FREE BREATHER" PRINCIPLE TO CARGO CONTAINER FOR THE PREVENTION OF CORROSION OF MILITARY CARGOES

Jules A. Vickness

U. S. ARMY TRANSPORTATION RESEARCH COMMAND

Fort Eustis, Virginia

O

APPLICATION OF "FREE BREATHER" PRINCIPLE TO CARGO CONTAINERS FOR THE PREVENTION OF CORROSION OF MILITARY CARGOES

The Transportation Corps operates a fleet of approximately 80,000 reusable steel shipping containers, known as "CONEX". By providing physical protection to the container contents, substantial reductions in levels of packaging and packing become possible, with resulting dollar savings.

SLIDE*

The CONEX unit is 8 feet 6 inches long, 6 feet 3 inches wide, and 6 feet 10-1/2 inches high. It has an internal volume of 295 cubic feet and is constructed of corrugated steel panels. It is designed to be weathertight, with provisions for ventilation at the valleys of the corrugations where side and rear end panels join the top and bottom. In addition, the doors are provided with a labyrinth arrangement around their peripheries which permits the run-off of rain without sealing.

Our CONEX was extremely successful when used for general cargo. However, it soon became evident that there were classes of military commodities that, by virtue of their high susceptibility to corrosion, were being expensively preserved and packaged and therefore did not move in CONEX; or when they did, they moved at less than optimum efficiency.

It was postulated that, if a reasonable method could be found whereby a low-humidity internal environment could be maintained within a CONEX-type container during the in-transit period for such commodities, a substantial saving could be obtained by reducing the levels of preservation and packaging of items susceptible to deterioration from humidity.

An initial evaluation of this problem in relation to CONEX indicated several possible approaches.

*Slides are available on a loan basis from U. S. Army Transportation Research Command, Fort Eustis, Virginia.

1. Alter the CONEX design to provide a completely sealed unit or pressure vessel. The container could then be charged to a pressure of 3 to 5 p.s.i.; and by using a dry charge of gas and by simple gaging, the enclosed environment could be controlled to safe levels of humidity. The obvious disadvantage to this technique is the additional structural requirements for such a unit, with the attending increase in weight and cost.

2. Another approach which was examined called for modifying the present CONEX to effect a seal of all openings, statically desiccating the interior by use of a chemical agent such as silica gel, and providing for pressure differentials which could be caused by inside-outside temperature changes by using a 2-way pressure relief valve. It was found that a 1-p.s.i. valve was the lowest available and that without substantial modification the standard CONEX could not withstand this pressure.

3. These analyses led to a third possible approach, that of a "Free Breather". It is the successful application of this principle that I wish to bring to your attention.

In 1947 the Naval Gun Factory conducted a series of tests to determine the practicability of utilizing silica gel, vapor pressure inhibitor agents, and breather devices in various combinations as a means for preventing the formation of corrosion and the propagation of fungi on internal susceptible components of enclosed Ordnance instruments. The instruments were subjected to cycling tests at high and low temperatures under high humidity conditions.

SLIDE

In the utilization of silica gel for container dehydration, design experiments revealed that by preventing direct access of external air to the silica-gel unit and by restricting the contact of air with the gel in the cell, by means of a breather tube, to the amount of air that was thermodynamically pumped (due to daily temperature changes) in and out of the box, the life of the silica gel was greatly extended. In tests, a tube nest composed of sufficient tubes having a length-to-bore-diameter ratio of about 10 to 1 and having sufficient total cross section area to allow reasonably free breathing capacity (to handle volumes expired or inhaled during air lift without excessive internal/external pressure differential) proved to be an effective and economical design.

The potential of the application of this principle to CONEX was quickly recognized, and it was this approach which was finally selected.

Since initial experiments were conducted with 1 - 2 cubic foot units under conditions which did not parallel those envisioned for CONEX, a program was initiated to determine the following:

1. Proper breather tube configuration that, under various conditions, would permit a rate of air passage through it which would provide for pressure equalization (necessary to keep container structure to reasonable levels).

2. Extent to which a properly configurated breather tube would reduce the relative humidity of inhaled air when pressure differential causes air to flow into the container (necessary to determine the amount of assistance through silica gel which would be required to maintain safe relative humidity).

3. Period of time that the breather, when augmented by a charge of silica gel, would provide a safe environment (necessary to determine life expectancy of the dessiccant charge before its replacement becomes necessary).

Two essential conditions were believed to govern these determinations. One is that of the air transmission rate of the breather, or the ability to relieve pressure or vacuum within a CONEX brought about by changes in altitude and temperature during an air flight. For this condition, tests were conducted in which the flow of air that would result from a container's being transported by aircraft between sea level and 25,000 feet was simulated to determine whether breather units of proper design would prevent the creation of pressures or vacuums within the CONEX which would cause structural failure.

SLIDE

To determine accurately the maximum rate of flow, the temperature, pressure, and density of air at various altitudes were tabulated. The weight of air lost between each elevation was computed and converted to volume of air lost between each elevation.

SLIDE

By relating this to a typical ascent curve, it was found that the maximum rate would be approximately 21.15 cubic feet per minute for an empty container. Since it could be reasoned that the container would almost always be shipped in a loaded condition, we arbitrarily set the condition of loading at one-third full. The volume of air in the container then would equal two-thirds of 295, or 197 cubic feet. The maximum rate of flow would then equal two-thirds of 21.15, or 14.1 cubic feet per minute. It could be assumed, therefore, that the breather unit would be considered satisfactory if it could pass 14.1 cubic feet per minute at a pressure of less than 1 p.s.i.

To determine whether the rate of flow would be affected by the moisture content of the air, by the degree of saturation of the desiccant in the breather cell, or by the direction of flow, tests in sufficient variations to permit comparisons of these effects were conducted.

SLIDE

The test apparatus was planned so as to permit a variation in the rate of flow of air through the breather depending upon a variation in air pressure. Tests were performed on breather units with dry desiccant (not more than 10 percent by weight of water) and on breather units with spent desiccant (containing approximately 25 percent by weight of water or when moist air cannot be reduced in humidity to 40-percent relative humidity).

By reversing the breather end for end, direction of air flow could be changed. Breather tube plates of different configurations and desiccant beds of several diameters or lengths were included for comparison.

To determine the moisture absorption rate or life expectancy, breather units were subjected to a flow of air which simulated field conditions. By passing known volumes of air at known temperatures and humidities through the breather, prediction data were obtained. As previously mentioned, the most difficult conditions are those of exposure in a tropical, rainy climate. Assuming an average ambient high of 95°F.,* interior temperatures of 116°F. in an olive-drab container and 102°F. in an aluminum or aluminum-color unit are possible. It should be noted here that during the high temperature of daylight, the air in the containers is being driven out through the breather; and because of the high temperature, the relative humidity is comparatively low.

* Berry, F. A., et al, Handbook of Meteorology, McGraw-Hill, New York, 1945.

During the tropical night, the temperature drops and the air within the container contracts and draws cooler, more humid air into the container. For the purpose of this test, tropical night air was assumed at 70° F. and 85 to 95 percent relative humidity.

An olive-drab container under average high ambient conditions in the tropics would expel an average of 17.3 cubic feet of air per day; an aluminum unit, 18.0 cubic feet per day. For test purposes, it was assumed that 17.3 cubic feet of air is driven out of the container during the tropical day when interior temperature is high and the relative humidity is low. This same volume of air is then drawn into the container through the breather unit during the tropical night, when the temperature is approximately 70° F. and the relative humidity is from 85 to 95 percent. It was further assumed that the air expelled through the breather unit is of sufficiently low humidity that it will not tax the desiccant.

As criteria, we concluded that a safe and reasonable condition would be maintained within the CONEX container if the humidity at 70° F. remained below 40-percent relative humidity. This would insure relative humidities at less than 40 percent for all but a few hours of each day and would insure against damaging effects of condensation within the container even though night temperatures fall as low as 45° F.

SLIDE

Daily fluctuations of temperature and relative humidity within a container in the tropics is shown in the table. It should be noted that if the relative humidity is kept below 40 percent at all times, when the average low temperature at night is 70° F., the relative humidity within the container will reach as low as 10 percent during the hot hours of the day. Condensation would not occur until temperature within the container dropped to 45° F.

SLIDE

A schematic of our test apparatus is shown here.

1. Source of air and air pressure - a 5-horsepower electrically operated air compressor capable of delivering air at a maximum rate of 20 cubic feet per minute. Maximum pressure of the air compressor tank is 60 pounds.

2. Pressure regulator valve - with a range 0 to 10 pounds.

3. Humidity tank - to add humidity to the air by means of a cylindrical galvanized tank. The tank is approximately 16 inches in diameter and 18 inches high. It is equipped with a thermostatically controlled immersion-type heater to control the tank water temperature between 100°F. and 160°F. The tank includes a relief valve set at 20 pounds.

4. Temperature tank - a rectangular galvanized tank 16 inches by 16 inches. Coiled copper tubing is wound in a 10-inch-diameter spiral and immersed in room-temperature water. Higher temperature can be produced by a thermostatically controlled immersion-type heater.

5. Dryer - to provide dry air for air transmission rate test. The dryer is a cylindrical tank 8 inches by 18 inches, containing 25 pounds of commercially dry desiccant. It is capable of reducing humidity of the air to less than 20-percent relative humidity.

6. Initial control chamber - a small cylindrical tank approximately 6 inches in diameter and 10 inches in length, fitted with a temperature indicator, a manometer, humidity indicators, a safety valve set to 5 p.s.i., and a petcock drain.

7. Rotameter - to permit instantaneous reading of the rate of flow of air through the system. The device consists of a metal float in a tapered glass tube, and operates on the principle that a higher rate of flow of air will lift the float higher in the tube. Since readings for air-flight tests were in the high range and readings for the tropical tests were in the low range, two floats and two calibrated scales were used.

8. Flow meter - used for measuring the total volume of air passing through the system within a given time. It has a capacity of 400 cubic feet per hour at a 1/2-inch pressure differential and 900 cubic feet per hour at a 2-inch pressure differential. It was also used to recalibrate the rotameter. At very low rates of flow, readings were taken by means of the flow meter and a stop watch.

9. Second control chamber - same as the first except that it is fitted with only a temperature indicator, humidity sensing elements, and a drain opening.

10. Breather duct - used to house the breather test unit. It is fitted with a cap or bonnet to carry the air through the breather units and to maintain a closed system. Manometers were placed close to the entrance and exit of the breather duct.

11. Gages - temperature gages used are of the bimetal thermocouple type with a range of 0° to 125° F. Manometers are of the mercury U-type, with a range of 12 inches of mercury (approximately 6 p.s.i.), and can be accurately read at pressures as low as 0.01 inch of mercury. Humidity sensing elements are Aminco-Dunmore make, and are read with an a.-c. operated Aminco Hygrometer.

To determine the effect of certain conditions on the flow of air through the breather and to derive data for use in the development of the breather design, a series of 22 tests as previously shown was conducted. The condition of the air and desiccant and the direction of flow were varied. Combinations of breather and breather tubes were used. Three or more readings were taken for each condition. Pressure readings were corrected to take into account barometric readings and altitude. The following curves represent our findings in relation to air flow.

SLIDE

Tests 1 and 2 indicate that a one-tube plate will not permit the required flow (14.1 cubic feet per minute) under a pressure differential of 1 p.s.i. Test 3 indicates that a four-tube plate would just barely pass a sufficient amount of air. Test 10 shows that a tube plate with 5-1/4-inch-diameter openings will suffice.

SLIDE

A comparison of the rate of flow through a 4-1/2-inch-diameter breather and a 6-inch-diameter breather in conjunction with several tube plates is shown in this slide. It can be seen that the 6-inch diameter is necessary for proper design.

SLIDE

In this chart, several curves have been plotted to show the rate of air flow through breathers and breather plates in opposite directions. It can be seen that the rate of flow in opposite directions is so near to being the same as to be inconsequential.

SLIDE

The next chart is a comparison of the flow of dry and moist air. The flow of dry and moist air through both a dry breather and a spent breather is included. Again it can be seen that the differences in the flow of dry and moist air are insignificant.

SLIDE

This chart shows a comparison of the rate of air flow through a dry desiccant bed and through a spent desiccant bed. Here it can be seen that the rate of flow through a spent desiccant appears to be significantly greater than that through a dry desiccant. The explanation is not readily apparent. Since the desiccant bed was spent by passing a large volume of moist air through it at a rapid rate, it is possible that channels were formed either mechanically or by evaporation, the channels permitting easier passage through the spent bed.

As previously mentioned, a CONEX container with one-third of its volume filled with cargo can be expected to breathe approximately 17.3 cubic feet of air each day in the tropics. The rate of passage has been

approximated at 0. 07 cubic foot per minute and preliminary testing shows that this could be accelerated to 1. 0 cubic foot per minute without affecting test results.

To simulate a period of storage in the tropics, air was passed through the breather unit at a humidity ranging from 85- to 95-percent relative humidity and at a temperature of approximately 70° F. The temperature of the exhausting air was slightly higher than that of the air being introduced because of the heat that was generated within the desiccant bed during the action in which moisture was absorbed into the desiccant crystals.

During the test, air was permitted to flow continuously through the desiccant bed. Conditions were kept reasonably constant, and readings were taken approximately every 3 hours, day and night. The introduced air averaged 71. 9° F. and 90 percent relative humidity. The average temperature of expelled air was 76. 8° F. The tests were continued until the humidity of the air coming out of the breather exceeded 40 percent relative humidity. When the breather unit desiccant was weighed at the conclusion of the test, it was found to contain 24. 4 percent by weight of moisture.

SLIDE

The data, then, are plotted here. Slight fluctuations in the curve are due to the relative interdependence between relative humidity and temperature. Larger fluctuations in the curve are due to day and night changes in the temperature of the air drawn into the compressor and to day and night changes in the temperature of pipe and duct work.

It can be seen from this chart that the desiccant within the breather was not spent until about 4, 320 cubic feet of air had passed through the bed at a rate of 17. 3 cubic feet of air per day. This represents approximately 250 days, or 8. 2 months, of effective operations before the desiccant could be considered spent. If it were assumed that the container was aluminum rather than olive drab and the rate of breathing only approximately 12 cubic feet per day, the breather unit would be effective for a period of approximately 360 days.

Similarly, if the container was considered to be two-thirds full of cargo rather than one-third full, the life expectancy would be even greater--for olive drab, approximately 496 days; for aluminum, 720 days.

From the preceding research and testing, we concluded that:

1. The CONEX container either with minor modification or with redesign is suitable as a dehumidified container.

2. The desired objective can be accomplished without making the container absolutely airtight by permitting the container to breathe through breather tubes and a desiccant bed.

3. Breather tubes whose lengths are 10 times their diameters are capable of reducing humidity of the air by approximately 15 percent or more before the air reaches the desiccant bed.

4. A properly designed breather unit may be expected to maintain a safe humidity within the CONEX-type containers for all anticipated in-transit storage periods.

5. The "Free Breather" will maintain a nondestructively low internal humidity within a container in the presence of extreme humid external conditions that are specified in MIL Std 210-A and AR 705-15.

Based on these conclusions, a development program was initiated. Results of this development program are shown in the following slides.

SLIDES

TRANSPORTATION FORECAST AND PREDICTION STUDY

W. L. Garrison
Professor of Geography

NORTHWESTERN UNIVERSITY
Evanston, Illinois

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TRANSPORTATION FORECAST AND PREDICTION STUDY*

This paper provides an expository review of basic research relevant to the development of transportation systems undertaken by the Transportation Center at Northwestern University for the U. S. Army Transportation Research Command. Chief emphasis in the discussion is on the purpose and structure of the research.

HISTORY

During the summer of 1959 the Transportation Center undertook a study of the distribution of transportation resources or stocks among and within nations, and a report on that topic was submitted to the U. S. Army Transportation Research Command in July 1960.[1] Shortly thereafter the Transportation Center began a study of four years' duration for the purpose of more penetrating analysis of factors that condition the development of transportation systems. Work under this new contract gained momentum during the fall of 1960, and the first block of research under the current contract is the subject of an Interim Report to be submitted October 31, 1961.[2]

OBJECTIVE

The over-all objective of this research is the development of a workable theory which will explain transportation networks in the sense of the ensuing two sentences. (1) Given measures of those characteristics of an area upon which the level and character of transportation depend, a

*This paper is an adaption and extension of the Preface to materials to be submitted on October 31, 1961, to the U. S. Army Transportation Research Command, under the title The Structure of Transportation Networks, by the Transportation Center at Northwestern University under Contract DA 44-177-TC-685.

[1] Transportation Geography Research, a report prepared for the U. S. Army Transportation Research Command, Fort Eustis, Virginia, by the Transportation Center at Northwestern University, July 1, 1960, under Contract DA 44-177-TC-574.

[2] The Structure of Transportation Networks, op. cit.

systematic method is desired for stating the nature of transportation in that area. (2) Given a change in those characteristics of an area upon which transportation depends, it is desired to know how the transportation system will change. These two sentences state the requirements for a theory in the simplest possible way: a theory is desired that will allow us to deal with the phenomenon in which we are interested. The statements give considerable insight into the structure of the study. The phenomenon of interest is transportation, of course. By dealing with transportation we mean relating its level and character to those factors upon which transportation development depends. These notions are given greater substance in ensuing sections of the paper, which emphasize the functional dependence between transportation and the factors upon which it depends, and which emphasize various ways in which transportation phenomena may be studied.

USES OF RESULTS

Before going on to these two main topics, it might be wise to spend a moment on uses of results of this study. First, a workable theory has obvious value for long-range predictions and attendant planning. For instance, it is known that the nature of transportation in an area is closely related to the level of economic development. Development is going on with rates varying among areas. What do we expect the transportation systems in these areas to be like 5, 10, 15, and 25 years ahead? The theory provides a part of the decision systems required to treat such a question.

There is a second value of a theory that is more indirect and more difficult to state, but this may well be its greater value. In day-to-day transportation work we deal with a whole series of seemingly isolated questions. What is a good method for classifying commodities? What is the value of increasing the capacity of a link of a particular transportation system? Is A more accessible to the transportation network than B? In areas of work where a well developed theory is available, it has been found that the theory provides a useful guide to answers to seemingly isolated questions. There is every reason to believe that insights provided by general theory of the development of transportation systems will provide a useful guide for finding meaningful answers to many of our questions (and a useful guide for asking meaningful questions).

The two remaining sections of this paper will serve to answer two questions: (1) What do we mean by a functional relationship between transportation and those characteristics of areas upon which transportation depends? (2) How can the word transportation be made operational

in the context of these dependencies? These sections give additional definition to the research problem and the structure of the studies.

TRANSPORTATION, A FUNCTION OF THE CHARACTERISTICS OF AREAS

In the introduction to our first report[3] it was pointed out that the surface transportation development of any country depends upon:

1. General economic development.
2. Natural environment.
3. Location of activities.
4. Available technology and relative cost structure.
5. The interests and preferences of those who make decisions affecting transportation.
6. Military and political influences.
7. The historical pattern of development and outlook for the future.

This list is not inviolable, and a knowledgeable person could extend or modify it in useful ways. For instance, one could extend the list to the subject of air transportation by mentioning the position of nations on international air routes. Though incomplete, the list serves an important purpose: It emphasizes that transportation development may be thought of as some function of characteristics of areas. By adopting this systematic view, transportation may be explained in relation to other matters and there is hope for development of the capability to forecast and evaluate transportation developments.

The notion of functional relationships given in the paragraph above is a very simple one, but its simplicity should not disguise its significance. There has been little work on transportation development topics from this point of view, but this point of view is basic to the present studies. Because of the lack of attention to external influences of which

[3] Transportation Geography Research, op. cit.

transportation is a function, our ability to make incisive statements of how and why transportation systems develop and what we anticipate in the way of development is small. In contrast, much useful work has been done on certain other transportation topics; for instance, knowledge of technical problems of construction is both voluminous and useful.

OPERATIONAL VIEWS OF TRANSPORTATION

The statement of functional relationships given above is too general to give much information regarding the substantive character of the research. Indeed, this research may be described as an attempt to give substance to statements of functional relationships, and the character of the research may be displayed by commenting upon the ways in which it has been found to be practicable (or is felt will be practicable) to give operational meaning to functional statements.

Transportation may be viewed in the following five ways:

1. Stock aggregates or transportation resources. Miles of road, number of cars, etc.

2. Structure or layout of transportation routes. What types of routes go where?

3. Flows. What goes where?

4. Intensity of use, or the transportation activity as a productive activity within an economy. What does transportation use as its inputs, and in what ways does it contribute to the output of the economy?

5. Relationships of transportation networks to each other. For instance, how does the railroad network relate to the highway network?

This list of ways in which transportation may be viewed gives operational ways to deal with the transportation portion of the statement that the transportation within an area is some function of conditions within the area. It might be noted at this time that by viewing transportation in several different ways, we have "disaggregated" the concept of transportation and the various views of transportation are not completely

independent. The layout of the transportation network is certainly dependent upon flows, for instance. Thus, viewing transportation in any one of these ways just listed requires that we add other aspects of transportation to the list of conditions controlling the characteristics of transportation systems. For instance, the layout of a transportation network is determined by such factors as topography and the like, and layout is also influenced by the relationships of networks to each other, flows, and other of the operational views of transportation.

The first two of the five operational views of transportation listed above were the objects of blocks of research that are largely complete; the remaining three are the objects of present and programmed research. The remainder of this paper consists of remarks intended to clarify these topics.

STOCKS

Variations in surface transportation stocks from nation to nation and within nations were the subject of a previous research report,[4] as was mentioned before. Consequently, it is possible to discuss research on this topic by giving a capsulized review of that report.

The research was divided into two parts, one of which was the comparison of surface transportation stock aggregates among nations. The term transportation stock refers to the facilities or resources through which transportation is carried on: cars, buses, trucks, rail passenger cars, rail freight cars, amount of road, and amount of railroad. These were treated as aggregates. For instance, all cars within a country were added together and the sum used as one object of the study. The second portion of the study treated the distribution of highways within nations.

Variations in transportation stocks among nations were related to a set of explanatory variables, including population, area, gross domestic production, per capita income, population density, slope, and rainfall. A series of 75 regressions were made and given extensive interpretation. It was found that gross domestic production and income per capita are the chief determinants of levels of transportation stocks. However, the value of the study does not lie so much in this direct finding as it does in the identification of appropriate variables, magnitudes of regression

[4] Transportation Geography Research, op. cit.

coefficients, and magnitudes of errors of estimation that may be expected in dealing with stock aggregates.

The second portion of the study was addressed to the distribution of transportation facilities within nations. Four areas, Ghana, Nigeria, British East Africa, and Brazil, were used as cases in point. It was found that highway mileage in an area is related to the square root of the population of the area times the square root of the size of the area. Highway mileage also depends upon the availability of alternate types of transportation and local resources. Again, the value of the study is not so much in this direct finding as it is in the development and analysis of a device useable for estimating the occurrence of surface transportation facilities.

STRUCTURE

The term structure refers to the layout, network, geometry, or pattern of transportation facilities, and these words are used interchangeably. A block of research on the topic of structure has been completed and will be the subject of a forthcoming report.[5]

For this reason it is possible to discuss this topic by giving a thumbnail sketch of the research treated in that report.

The research on structure developed ways to find partial answers to three questions:

1. What measures will describe the structure of transportation networks?

   A number of measures of structure were developed and investigated. These measured characteristics of transportation networks such as number of points served, number of separate links, lengths of paths, tendency toward centrality, and the presence of alternate routes. These measures were then used in connection with question 2 below.

2. In what ways do measures of structure depend upon the characteristics of the area in which the transportation network lies?

   A number of regression studies were made and "strong"

[5] The structure of Transportation Networks, op. cit.

relationships were found between the measures of network structure and conditions such as the level of economic development of the area. The ability to answer the first two questions provides explicit ways to codify the structure of transportation systems, and to relate structure to the characteristics of areas.

3. Given knowledge of measures of network structure, can the transportation network be mapped?

   Empirical studies were made of features of networks and of the development of particular transportation networks. While the answer to this question is a tentative yes, additional work needs to be done with question 3.

Stated in other words, the ability to answer these three questions provides a way to evaluate transportation networks in two stages. First, given some information on the nature of an area, it is possible to estimate certain measures of the structure of transportation in that area. Second, it is possible to map the transportation system by using these measures of structure. This provides a way of understanding how transportation networks change following changes in the characteristics of the areas in which they lie.

FLOWS

The term flows refers simply to the movement of persons, commodities, or messages; flows are the activity of transportation. The fact that so many flows may be identified presents a chief problem in the systematic study of flow systems. This problem is one of finding incisive measures of flows that are useful in a sense that they are both (1) related to determining variables and (2) general and of wide applicability. The ability to relate measures of flows to explanatory variables is necessary if functional statements are to be made about flow systems and if methods are to be developed for the short- and long-run forecasting of flow characteristics of transport systems. Measures of flows must be incisive so that once these measures are accomplished they, in turn, will yield information about any particular type of flow that it might be desired to study.

The study of flow systems is part of our current research, and research results cannot be stated at this time. It is possible to mention here, however, certain expectations of fruitful results from the study of flows. For one, there is a small but useful literature that treats flow systems

using the mathematics of linear programming and, in some instances, using economic concepts such as comparative advantage, factor price equilibrium, interregional equilibrium, etc. The generality and preciseness of this approach strongly infers that it will provide systematic measures of flow conditions and methods of relating these flow conditions to external variables.

A second approach that promises to be useful makes use of the temporal sequence of flow activities. Transportation activities may be characterized, for instance, by the proportion of time that they are operating at capacity. This useful measure would seem to be directly related to such external variables as the agricultural industry of a nation, industrial mix, and production characteristics. In turn, this measure would provide considerable information on the transportation system itself--type of system and equipment used, efficiency, etc.

INTENSITY

The functioning of a national economy requires the use of transportation. It is common knowledge that specialized production increases when economies develop and more transportation is required. The research question is that of the manner in which economies with different structures vary in their use of transportation, and the relationships between these variations and other determinants of transportation systems.

This problem demands more sophisticated study and introduces more problems than might be assumed at first glance. In part, this is because of the many ways transportation is used in an economy. One might prepare a list of all outputs of the economy--beef, steel rails, automobiles, electric motors, etc.--and the transportation required per unit of output for each of these outputs might be stated. A convenient measure might be the monetary value of transportation required for each dollar's worth of output of each commodity. The measure of transportation intensity of a country is, then, a list of numbers showing the input of transportation per unit of output for activities. A set of measures would consist of a set of lists, one list for each nation. We are now faced by the problem of how these lists differ from nation to nation and how these differences may be explained by functional relations.

Each of these lists of numbers may be viewed as a vector, and the technical problem of working with vector measurements is not great. Experience indicates that a more difficult aspect of the research will

be that of finding the measures that are the elements of the individual vectors. A set of vector measurements for Japan, Italy, and the United States was presented in a previous monograph,[6] and similar data are available for a number of other nations. However, anyone familiar with statistics of this type would realize that there are very serious questions of the comparability of these data. A chief research problem will be that of assuring comparable statistics.

RELATIONS OF NETWORKS TO EACH OTHER

This topic differs somewhat from the preceding four topics in that it is concerned with the relationships among transportation systems rather than being one way the notion of transportation may be codified. A well-known subject is that of the relationships between highway networks and railroad networks. In certain areas, the highway network is supplementary to the railroad network. In others, the highway network both supplements and complements or competes with the railroad network. These network relations are evidenced by and a consequence of stock conditions, characteristics of flows, network structure, and use characteristics described earlier. Research is programmed on the topic because it complements the four research topics discussed above.

SUMMARY

This paper has provided an overview, albeit sketchy, of the structure of and progress on a study of certain basic aspects of the development of transportation networks. It was noted that the level and character of transportation development are viewed as a function of certain characteristics of the area containing that transportation. Five ways in which transportation development can be given operational meaning were also discussed.

[6] Transportation Geography Research, op. cit., p. 17, Table IV

ENVIRONMENTAL ANALYSIS OF THE GROUND EFFECT MACHINE

William J. Neff

BOOZ-ALLEN APPLIED RESEARCH, INC.

Bethesda, Maryland

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INTRODUCTION AND BACKGROUND

This paper is based on a study recently completed by Booz-Allen Applied Research, Inc. The purpose of the study was to analyze the total environmental picture surrounding the Ground Effect Machine (GEM) operated on a world-wide basis, and to classify a range of vehicles with operational capability in this environmental framework. In essence, it is the environmental approach to the vehicle.

The contract was funded by the U. S. Army Transportation Corps and administered by the Office of Naval Research as part of the joint research program on GEMs. Lt. Col. Joseph L. Wosser, USMC, was the Scientific Officer for the contract, Nonr 3375(00). The team participating in the study included P. G. Fielding - Project Director, P. J. Mettam, W. S. Bull, Jr., N. L. Hallanger, and W. J. Neff, under the supervision of C. F. Riley, Jr. - Research Director.

The Ground Effect Machine is basically a load-carrying vehicle, supported on a cushion of air between the vehicle and the surface. Extensive research programs on many phases of performance, structures, power requirements, stability, and control have been carried out, both in this country and abroad. Because of its apparent capability for operation over both land and water surfaces at speeds up to and exceeding 100 knots, the GEM has received favorable consideration for a number of military applications.

Our study was undertaken to determine the influence of the world-wide operating environment on the basic design, performance, and equipment requirements of GEMs. This included a review of all elements of climatic and geographical features relative to GEMs. We determined the influence of these features on vehicle parameters, and developed classifications of vehicles for overland, marine, and amphibious operations. We then reviewed the induced and combat environments associated with military GEMs, i.e., the induced environments resulting from the special characteristics of GEM operation and the combat environments resulting from the military operating situation. The nature and extent of the problems associated with these environments were determined. Finally, a brief performance analysis was carried out. Vehicles in each environmental category were compared for transportation efficiency, utility, and vulnerability, and the best vehicles in each category were pointed out.

WORLD-WIDE NATURAL ENVIRONMENT

The world-wide natural environment for GEM operations includes all the diverse characteristics of terrain, drainage features, vegetation, cultural features, beach conditions, sea states, and climatic elements. The unique nature of the GEM as a transportation vehicle requires a new approach to the evaluation of these environmental characteristics.

The analysis of environmental influence on the GEM is based on very broad assumptions about the characteristics of the vehicle. In essence, the vehicle characteristics are based on the present state of the art for GEMs. Two significant features of this state of the art are a limitation of operating height to about 10 percent of the vehicle's base dimensions and the limitation of maneuvering accelerations to about .1g to .2g

In order to provide consistent development for all categories of GEM operations, the following breakdown of natural environments was used:

1. Maritime environments covering the oceans of the world were used as a basis for marine GEM operations.

2. Coastal environments covering the ocean coasts of world continents were used as a basis for amphibious GEM operations.

3. Continental environments covering the world continents were used as a basis for overland GEM operations.

Some overlap is inherent in this division; however, this overlap was not considered to be objectionable in any way.

For each category of operations, the background data included all the physical features of the associated environment which were considered to have influence on the design and operating requirements of GEMs. The climatic elements included wind, temperature, precipitation, fog, thunderstorms, and sand and dust storms.

All world areas (except the oceans) were divided into climatic zones. The climatic zone breakdown together with political boundaries provided correlation of data for each area.

The sources of data included the military geography chapters of the National Intelligence Surveys, the Oceanographic and Marine Climatic Atlases, Geography Atlases and Texts, and Climatic Texts. Other data were made available by the U. S. Navy Hydrographic Office, U. S. Navy Weather Research Facility, Office of Naval Intelligence, U. S. Weather Bureau, Army Map Service, and Military Geology Branch of the U. S. Geological Survey. Since some of these data are classified, the environmental data used in this study were assembled in a classified appendix to the project report.

OVERLAND OPERATIONS

The elements of continental environments considered to be most significant for overland GEM operations include altitude, slope, drainage features, vegetation, and terrain obstacles and discontinuities, such as irrigation features, embankments, walls, and hedges. The influence of these elements on GEM operations is as follows:

1. Altitude affects power requirements. However, because of the steep slopes at high altitudes, 90 percent of overland GEM operations would be at altitudes of less than 3,000 feet.

2. Slope also affects power requirements. Since the GEM has no surface contact to provide traction, the propulsion system must supply the force for operating up, down, and across slopes. Slopes of 0 to 10 percent occur over 58 percent of the world's land area. Slopes of 10 to 30 percent occur over 23 percent of the world's land area, and slopes of greater than 30 percent occur over 19 percent.

3. Stream valleys and other drainage features provide important access routes but limit vehicle size. GEMs can operate effectively on streams wider than three to four times the width of the vehicle. Most streams throughout the world are 60 to 250 feet wide; three-fourths are greater than 100 feet wide. Two-thirds of the streams have "steep" banks, across which GEM access to stream valleys would be very limited.

4. The occurrence of bends in rivers combined with the low acceleration capability of GEMs limits speeds for waterways operations.

5. Vegetation is an obstruction where it is tall and dense. Dense forest covers 24 percent of the world's land area.

6. Obstructions and discontinuities include solid obstacles such as walls, embankments, and buildings; yielding-nonpassable obstacles such as brush; and yielding-passable obstacles such as light fences and fields of grain. More data are needed on maneuvering requirements for overland GEM operations because of the high speed capability of these vehicles.

7. Irrigation ditches are commonly 2 to 10 feet deep and 4 to 30 feet wide. Rice paddies are commonly 100 feet square with dikes

2 feet high and 2 feet wide. Rail and road embankments are commonly 2 to 6 feet high.

The design limits imposed on overland GEMs by these environmental elements are summarized below:

Size (width)	20 feet on 95 percent of streams, and forest clearings. 30 feet on 75 percent of streams.
Operating Height	1 foot - limited local operations. 2 feet - overland, with detours. 3 feet - overland, fewer detours.
Jump Capability	4 feet - minimum for crossing dikes and walls. 6 feet - better for dikes and walls.
Stream Access	5-foot vertical bank capability up and down. 10-foot bank with slope of 50 to 100 percent.
Slope	15 percent for limited operations. 30 percent, at reduced speed, for general operations.
Speed	30 to 40 knots on majority of rivers, also reduced by obstacles overland (extent not known).

The suggested classification of overland GEM vehicles is shown in Table 1. The five classes listed in the table cover a wide range of possible sizes and operating heights. The planform ratio of 2:1 represents a fair compromise between utility and performance. (For performance determination, the vehicle size is most conveniently represented by the diameter of the circle having the same area as the base planform.) The operating height corresponds to the maximum practical height/base diameter ratios which can presently be achieved, except that operating heights greater than 3 feet do not provide significant added capability. The columns on inland waterways usable and access to stream valleys give the percentage along the length of streams suitable for GEM operations.

The overall suitability for overland GEM operations is given in Figure 1. Four qualitative categories of suitability are based on the geographic elements previously discussed. Unlimited overland operations correspond to areas which are mostly flat, barren, or grass covered with few obstacles.

TABLE 1
OVERLAND GEM CLASSIFICATION

Class	Size (ft.)	Operating Height (ft.)	Jump Capa-bility (ft.)	Slope Capa-bility (pct.)	Land Area Usable (pct.)	Inland Water-ways Usable (pct.)	Access To Stream Valleys (pct.)
I.	10 x 20	1	2	15	6	90	5
II.	20 x 40	2	4	20-30	18	90	20
III.	30 x 60	3	6	30	34	75	30
IV.	40 x 80	3	6	30	32	60	30
V.	50 x 100	3	6	30	28	50	25

Limited overland operations correspond to flat and partly hilly areas covered by brush or grass with stream valleys partly usable and not forming barriers. Operations on inland waterways correspond to forested and rough areas with wide streams providing access. In some areas operations may be restricted to the water area only. No operations can be carried out in rough and forested areas with few streams, except in very limited local areas. Operations in coastal areas are not included in this figure (they will be discussed later). The suitability classification given in this figure is very generalized and is not intended to indicate suitability for an operation at a specific location.

Altogether, about 50 percent of the world's land area is suitable for at least limited overland GEM operations. In addition, about 15 percent of the world's land area is suitable for operations on inland waterways only. Limited operations may be carried out on the icecaps of Greenland and Antarctica if special equipment is used.

The following generalized operating conditions may be seen in Figure 1: (1) A waterways operations belt stretches across the USSR through a forested region. In this region, wide north-south rivers are separated by 30 to 100 miles; (2) Operations are possible in the northern tundra regions whether thawed or frozen; (3) GEM overland operations are most suitable in Australia and Africa, and in South America if the Amazon Waterways area is included. GEM operations are not suitable to as large an extent in Asia and North America.

MARINE GEM OPERATIONS

The elements of the maritime environments most significant to GEMs are wave heights, winds, and occurrence of sea ice. The highest waves and winds normally occur in latitudes 40° to 65° North and South, oriented in bands east and west in the southern hemisphere and southwest to northeast in the northern hemisphere.

The lowest winds and waves generally occur in the low latitudes. Sea ice occurs in the North Atlantic in the winter and to a much lesser extent in the summer, but very little occurs in the North Pacific. Sea ice occurs year around near Antarctica.

The effects of these elements of maritime environments on marine GEM operations are as follows:

1. Wave height influences GEM operating height. We have used the relation of operating height equal to one-half wave height.

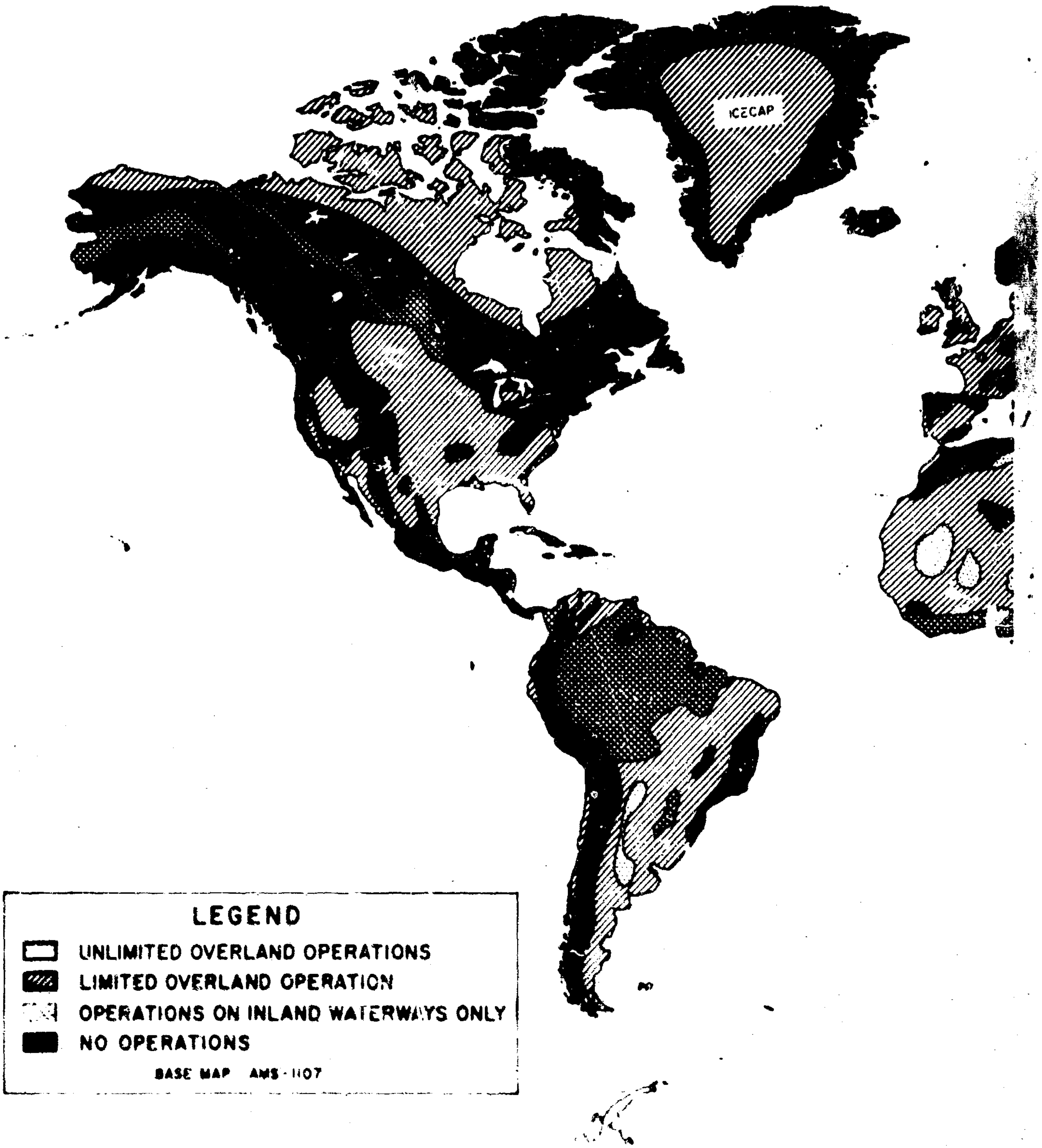

Figure 1. Suitability For Ove

-land GEM Operations.

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Wave-height maps made up from the Marine Climatic Atlases can be used to determine the ocean areas suitable for operations of GEMs of various sizes.

2. Sea ice, rough at the edges and when piled up near the shore, also influences required operating height.

3. Winds influence control power and block speeds which may be achieved on oceanic routes.

In coastal waters wave heights are generally lower; but surf, ice, wind, and channels will affect GEM operations.

The suggested classification of marine GEMs is given in Table 2. Here, again, we have chosen five classes of vehicles covering a range of sizes and associated operating heights. In addition, there is an alternate classification for "sidewall" marine GEMs, which utilize solid walls or skegs along part of the vehicle base to contain the air cushion. Lifting power requirements for sidewall GEMs are lower than those for standard GEM configurations; however, speeds will be limited by wave drag on the skegs. Pending further test results, sidewall marine GEMs are classified on the same basis as other configurations.

For each class of marine GEMs, the total power requirements at the normal cruise height for each class and at the maximum cruise height (at one-half to two-thirds normal cruise speed) are approximately the same. Seasonal feasibility is best determined by matching the normal cruise heights and maximum cruise heights with maps showing wave-height distribution on a seasonal basis. For example, a GEM with a maximum cruise height of 6 feet can operate on an annual basis 70 percent of the time in 80 percent of the world's oceans. The design winds for operation are the winds occurring at least 10 percent of the time in areas with wave heights corresponding to the maximum cruise heights.

AMPHIBIOUS OPERATIONS

Amphibious operations, corresponding to the coastal environments of the world, overlap to some degree both marine and overland operations. The significant elements of coastal environments include coastal terrain, stream valleys, characteristics of beaches, vegetation, surf conditions, and approach obstructions.

TABLE 2
MARINE GEM CLASSIFICATION

Class	Size (ft.)	Normal Cruise Height (ft.)	Max. Cruise Height (1/2-2/3 Cruise Speed) (ft.)	Seasonal Feasibility	Design Wind for Operations (k.)	Sidewall Configurations: Class	Sidewall Configurations: Base Clearance Height (ft.)	Sidewall Configurations: Seasonal Feasibility
I.	20 x 40	1	1.5	Choose operating area in Table of Summary Wave Height Data and match normal and max. cruise heights.	15	I-A	1.5	Choose operating area in Table of Summary Wave Height Data and match base clearance height.
II.	30 x 60	1.5	2.5		20	II-A	2.5	
III.	50 x 100	2.5	4		30	III-A	4	
VI.	75 x 150	4	6		30	IV-A	6	
V.	100 x 200	6	10		40	V-A	10	

1. Coastal terrain determines areas which are restricted from GEM operations. These areas include rocky and cliffed coasts.

2. Stream valleys provide access routes inland but, as in the case of overland operations, restrict vehicle size somewhat. Eighty percent of coastal streams are greater than 100 feet wide, 70 percent greater than 150 feet wide, and 50 percent greater than 250 feet wide. "Steep" banks occur on about 20 percent of coastal streams within 15 to 20 miles of the shore.

3. Wave heights and surf determine operating heights. Throughout the year, surf greater than 5 feet occurs on 90 percent of the world's coast, surf greater than 8 feet on 30 percent, and surf greater than 12 feet on 5 percent. Again, we have used the assumption that GEM operating height equals one-half surf height. More data are needed to support this assumption. Specifically, full-scale experiments on GEM operations in the surf zone should be conducted.

4. Surface-piercing water obstructions, including coral, are widely scattered along most of the world's coastlines but do not appear to offer much problem for GEM operations.

5. The characteristics of beaches that are significant to GEM operations include length, width, slope, and material. Only partial data coverage are available for beach characteristics throughout the world. Our analysis was based on the study of approximately 7,000 beaches in groups of 5 to 100. Length of beaches affects the size of operations: 45 percent of the world's beaches are greater than 2 miles long. Width of beaches affects unloading operations: 70 percent of the world's beaches are greater than 50 feet wide at high tide, but only 25 percent of the world's beaches are greater than 100 feet wide at high tide. Vehicle widths would thus be limited for unloading operations entirely on dry land. Slopes of beaches influence power requirements: average beach slopes are 3 percent in the tidal zone and 6 percent above the high-water line. Eighty percent of the world's beaches have maximum slopes of less than 10 percent, and 90 percent have slopes of less than 15 percent. Near-beach terrain has less than 15 percent slope for the most part (or rocky and cliffed, unsuitable for GEMs anyhow). Ninety percent of the world's beaches are composed of sand, pebbles, cobbles, and coral. Walls and embankments often back beaches, and thus prevent inland exit by vehicles such as GEMs.

6. Vegetation, surface cover, and terrain obstructions are the same as discussed in overland operations.

The effects of coastal environments on amphibious GEM operations are summarized below:

Size (width)	30 feet on 80 to 90 percent of coastal streams. 40 feet on 70 percent of coastal streams. 50 to 60 feet on 50 percent of coastal streams. For unloading at high water, 50 feet on 70 percent of beaches. 100 feet on 25 percent. 20 feet for operations in forest clearing. Size may also be limited by transportability requirements.
Operating Height	1 foot - to the beach only. 2 feet - limited inland penetration.
Jump Capability	4 feet - minimum for dikes, walls. 6 feet - better for dikes, walls.
Surf (maximum operating height)	2.5 feet on 10 percent of beaches. 4 feet on 70 percent of beaches. 6 feet on 95 percent of beaches. (not including storms)
Slope	10 percent for 80 percent of beaches. 15 percent for 90 percent of beaches, also near-coast terrain.
Stream Access	5-foot, vertical bank. 10-foot, 50 to 100 percent bank.
Speed	In coastal swamp areas, approximately 30 knots. Inland limited by obstacles (extent not known).

The suggested classification of amphibious GEMs is given in Table 3. The normal operating height corresponds to over the beach and overland operations. The maximum height corresponds to operations in the surf zone at approximately one-half normal speed. The numbers for access to beaches and access inland via stream valleys correspond to the percentage of world coastlines, excluding Antarctica, Greenland, and the North American arctic islands. These percentages include year-round operations except in storms.

TABLE 3
AMPHIBIOUS GEM CLASSIFICATION

Class	Size (ft.)	Normal Height (ft.)	Max. Height (ft.)	Jump Capability (ft.)	Slope Capability (pct.)	Access to Beaches (pct.)	Access Inland Via Stream Valley (pct.)
I.	20 x 40	1.5	2.5	3	10	10	10
II.	30 x 60	2	3	4	15	40	25
III.	40 x 80	3	5	6	15	70	40
IV.	50 x 100	3	5	6	15	70	35
V.	75 x 150	4	6	6	15	50	30

The generalized suitability for amphibious GEM operations is shown in Figure 2. In this figure the coasts of the world are divided into three categories of suitability: Zone 1 - GEM operations over the beach or inland via stream valleys; Zone 2 - GEM operations to the beach but inland access restricted; Zone 3 - unsuited for amphibious GEM operations. Zone 1 and 2 areas are subject to climatic limitations such as hummocked ice in winter.

Altogether, about 30 percent of the world's coastlines (excluding Antarctica, Greenland, and the North American arctic islands) are included in Zone 1, about 40 percent in Zone 2, and about 30 percent in Zone 3. Remember that this figure shows area coverage for generalized operating suitability and not point locations for specific operations.

INDUCED ENVIRONMENTS

Induced environments are the conditions arising during the operation of the system. These conditions interact with the natural environment in which the operation is conducted. The following elements of induced environments of the GEM were considered in our study:

1. Noise
2. Vibration: power unit induced, lift system induced, shock induced.
3. Component - generated temperatures
4. Exhaust gases
5. Static electricity
6. Visibility
7. Acceleration and shock, including stressing for wave impacts
8. Re-ingestion of downwash air, resulting in salt encrustation, erosion, icing
9. Salt water ingestion
10. Sand and dust ingestion
11. Snow and ice accumulation

Our conclusions on the elements of induced environments are that noise, re-ingestion, and visibility at low speed are the most significant problems for GEMs. Snow and ice accumulation can also be serious.

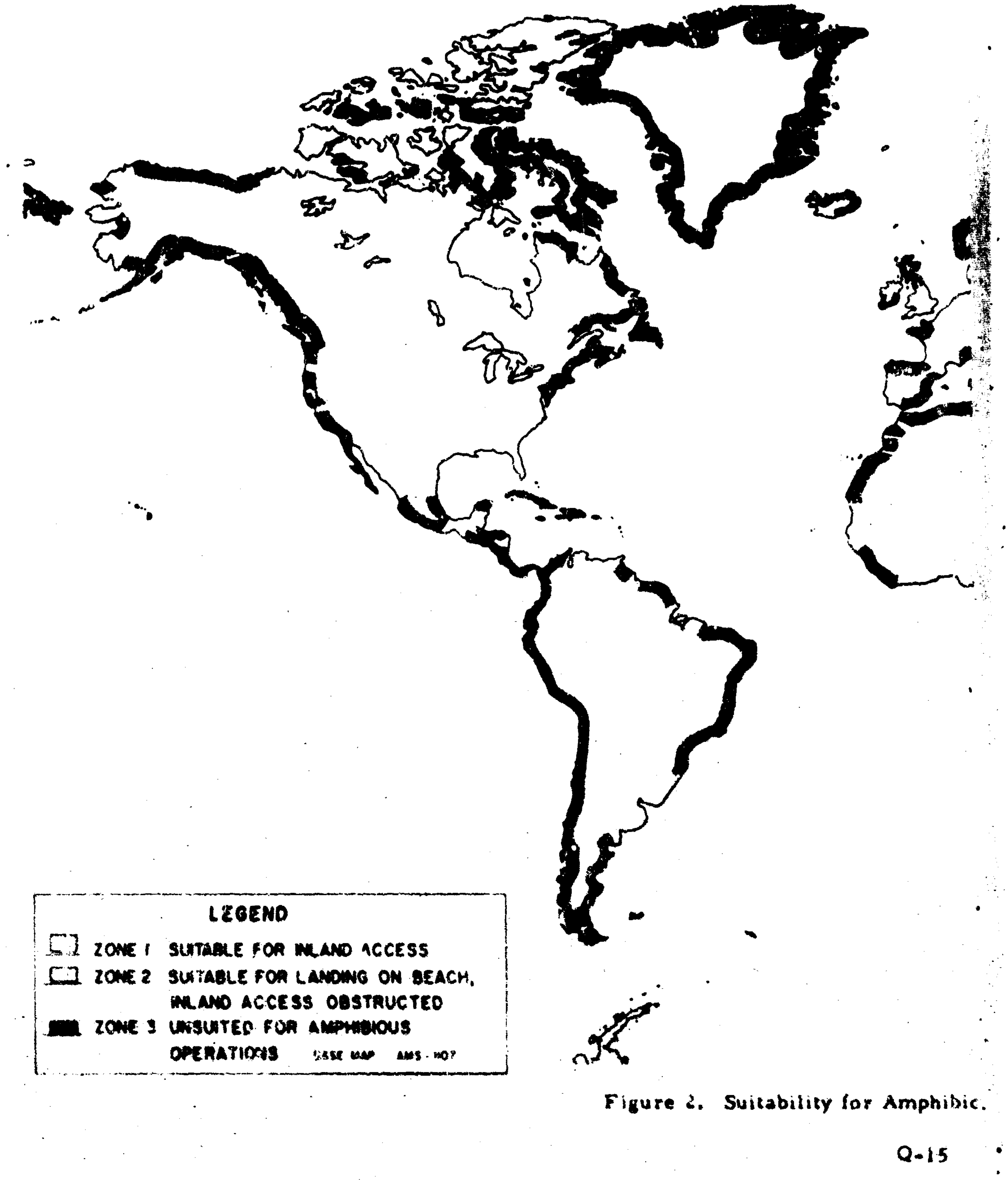

Figure 2. Suitability for Amphibic.

us GEM Operations.

COMBAT ENVIRONMENTS

The following elements of combat environments were considered:

1. Again, noise
2. Dust and spray
3. Camouflage
4. Radar reflectivity
5. Infrared emanation
6. Vulnerability
7. Damage protection
8. Field repairs
9. Operation in mine fields
10. Nuclear explosion environment
11. Loadability in marine and amphibious operations

Our conclusions here are that noise and infrared may be troublesome; also that a dust-cloud signature will be created during operations in arid regions

PERFORMANCE AND VEHICLE EVALUATION

Basic performance parameters were developed very briefly for all the GEMs classified above. This was not a detailed development of optimized performance. The results included weights, power requirements, speed capabilities, and payload-range parameters.

A comparative evaluation of GEM vehicles was based on transport efficiency (payload times range divided by fuel used), utility (operating areas from vehicle classification), and vulnerability (speed divided by size). Based on these criteria the following vehicles are best:

1. The GEM having the greatest potential for overland operations is a vehicle with a planform of 30 feet by 60 feet, an operating height of 3 feet, and a jump capability of 6 feet.

2. The GEM having the greatest potential for marine operations in the open ocean is a vehicle with a planform of 50 feet by 100 feet, a normal operating height of 2.5 feet and a maximum operating height of 4 feet.

3. The GEM having the greatest potential for marine operations in inland waterways and coastal waters is a vehicle having a

planform of 30 feet by 60 feet, a normal operating height of 1.5 feet, and a maximum operating height of 2.5 feet.

4. The GEM having the greatest potential for amphibious operations is a vehicle with a planform of 50 feet by 100 feet, a normal operating height of 3 feet, a maximum operating height of 5 feet, and a jump capability of 6 feet.

This is what we have called "the environmental approach to the vehicle". An overall analysis, such as that discussed in this paper, can serve to guide the development of new systems to meet the total environmental requirements with which they must be compatible. Detailed analyses of specific missions or operations can also be carried out. In the case of the GEM this is now being done to a limited extent.

The complete discussion, conclusions, and recommendations of our study were published by Booz-Allen Applied Research, Inc., in August 1961, in an unclassified report entitled "The Domain of the Ground Effect Machine". The Appendices containing background world-wide natural environment data were published separately as Volume II, classified Confidential.

ENVIRONMENTAL TESTING OF THE INTERNAL AUXILIARY COLLAPSIBLE PLASTIC TORSO (SEAT) TANKS DEVELOPED BY MARK XII, INC., REDONDO BEACH, CALIFORNIA, FOR THE U. S. ARMY UNDER CONTRACT DA 23-204-TC-1212

Mr. Paul L. Seabase
Director of Engineering

U. S. ARMY TRANSPORTATION MATERIEL COMMAND
St. Louis, Missouri

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ENVIRONMENTAL TESTING OF THE INTERNAL AUXILIARY COLLAPSIBLE PLASTIC TORSO (SEAT) TANKS DEVELOPED BY MARK XII, INC., REDONDO BEACH, CALIFORNIA, FOR THE U. S. ARMY UNDER CONTRACT DA 23-204-TC-1212

INTRODUCTION

The basic philosophy behind the subject development was the range extension of Army aircraft. In order to fulfill the requirements by the optimal compromise, the design was based on the following fundamental concepts:

1. Several tank units could be coupled to achieve any desired auxiliary tankage within certain limitations.

2. The weight of such a tank unit filled with fuel and oil would be approximately the weight of a fully combat equipped soldier.

3. The shape of a tank unit should simulate a human torso, and should consequently have the CG in the same place as a human.

4. The tank unit should have self-contained fuel and oil transfer implements.

5. The unit should be crashworthy in reference to "survivable" crashes.

From the consideration of these fundamental design concepts emerged the first form of this type of tank. At the very beginning it was obvious that the functionality of this new development would depend on environmental factors. Correspondingly, an engineering flight testing plan was set up, but with consideration of only a part of the environmental factors.

The collapsible version of the first development came as a subsequent phase in this developmental program. This was made possible by the introduction of a novel plastic material, which, corresponding to research data, showed an overall superiority of characteristics against formerly known materials and synthetic plastic materials. This material is polyurethane elastomer, commercially designated by its manufacturer, B. F. Goodrich, as "ESTANE." Though the material itself underwent a series of environmental static tests, it was of utmost importance to test the subject tanks within the environmental conditions which prevail in typical

missions utilizing the system. An environmental testing plan was set up and put into effect, ending with the engineering flight testing of the subject tank system. Though this investigation is not yet closed, the major part of it has been completed and an overall favorable picture is showing the rightfulness of the anticipated features.

TEST PLAN

Since the scope of the development primarily was the range extension of aircraft, consideration had to be given to the types of missions involved in this problem field. First of all, the deployment of Army aircraft had to be considered as having first-priority importance. However, the tactical exploitation of the range extension possibility was also set as an equivalently important goal. As usually occurs during a developmental program, additional requirements and features were added to the original basic concept.

At the beginning, the environmental testing had been divided into three major phases:

1. Static testing with induced environmental factors.
2. Flight testing with realistic environmental factors.
3. Destructive tests with simulated environmental factors.

Phase 1 has been practically concluded. Phases 2 and 3 have been concluded to their greater extent. The remaining portions will be accomplished late this year.

The three phases included the following specific tests:

1. Phase 1.
   a. Static testing with induced environmental factors.
   b. Climatic testing between -70°F. to +212°F. in a climatic test chamber.
   c. Testing of resistance against various fuels and solvents.
   d. Slosh and vibration test.
   e. Permeability test.

ENVIRONMENTAL TESTING OF THE INTERNAL AUXILIARY COLLAPSIBLE PLASTIC TORSO (SEAT) TANKS DEVELOPED BY MARK XII, INC., REDONDO BEACH, CALIFORNIA, FOR THE U. S. ARMY UNDER CONTRACT DA 23-204-TC-1212

INTRODUCTION

The basic philosophy behind the subject development was the range extension of Army aircraft. In order to fulfill the requirements by the optimal compromise, the design was based on the following fundamental concepts:

1. Several tank units could be coupled to achieve any desired auxiliary tankage within certain limitations.

2. The weight of such a tank unit filled with fuel and oil would be approximately the weight of a fully combat equipped soldier.

3. The shape of a tank unit should simulate a human torso, and should consequently have the CG in the same place as a human.

4. The tank unit should have self-contained fuel and oil transfer implements.

5. The unit should be crashworthy in reference to "survivable" crashes.

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f. Dynamic load test.

2. Phase 2.

a. Flight testing with realistic environmental factors.

b. Fuel transfer in flight at various altitudes.

c. Oil transfer at various altitudes.

d. Fuel drainage in flight.

e. Gravity refueling on ground.

f. Pressure refueling on ground.

g. Controllability of the aircraft with full tanks and with tanks half empty - stability of aircraft.

h. CG shift during fuel transfer - change of control forces.

i. Take-off with full fuel load.

j. Permeability and leakage test in flight.

3. Phase 3.

a. Destructive tests with simulated environmental conditions.

b. Simulated crash tests.

c. After-crash fire tests.

d. Dropability tests from various low altitudes.

TEST PROGRAM

The test program was initiated in November 1960. First the static environmental tests were performed. Part of the required test facilities were available at the ESTANE manufacturer's plant. Other tests were performed by the contractor at his own plant or at the facilities of a certified commercial organization.

missions utilizing the system. An environmental testing plan was set up and put into effect, ending with the engineering flight testing of the subject tank system. Though this investigation is not yet closed, the major part of it has been completed and an overall favorable picture is showing the rightfulness of the anticipated features.

TEST PLAN

Since the scope of the development primarily was the range extension of aircraft, consideration had to be given to the types of missions involved in this problem field. First of all, the deployment of Army aircraft had to be considered as having first-priority importance. However, the tactical exploitation of the range extension possibility was also set as an equivalently important goal. As usually occurs during a developmental program, additional requirements and features were added to the original basic concept.

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1. Phase 1.

    a. Static testing with induced environmental factors.

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    c. Testing of resistance against various fuels and solvents.

    d. Slosh and vibration test.

    e. Permeability test.

The climatic testing had an endurance of 160 hours. Also, the fuel and solvent resistance test series involved considerable time. Thus the results obtained can be accepted as realistic and conservative.

The dynamic load test was performed at the facilities of Hartmann Engineering, Inc., Los Angeles, California, on a pendulum-type test rig. The dynamic load test included all configurations specified by military specifications in the contract. The sequence of these tests is recorded on high-speed movie film (124 frames per second). Also, accelerometer readings were recorded on an oscillograph. After the contractually specified test load was applied and no failure occurred, the test was continued with stepwise increasing loads until failure occurred. The accelerometer readings refer only to the forward load. It is clearly visible in the film that before impact there was already a considerable load on the specimens from centrifugal acceleration. This fact shows that the load figures in this test are very conservative. The actual loads were larger, resulting from both horizontal impact and centrifugal acceleration. The test tank was filled with water to simulate the weight of the total fuel capacity. Consequently, at dynamic impact slosh was also in the play, and the pressure surges that followed and their effect could already be seen on both the high-speed movie and the oscillograph recordings.

The slosh and vibration test was performed in a test rig specifically designed for this purpose. The vibration frequency was approximately 60 cycles per second. This test was combined with the permeability and leakage test. The slosh and vibration rig was placed under a hood for the whole duration of 40 hours. Under the hood was placed the sensor of an explosiometer. This device would indicate not only the presence of an explosive fuel vapor air mix, but also the presence of any fuel vapor in the ambient atmosphere. During the 40 hours of this test, the vapor indication was constantly negative. For the slosh test, the test tank was only partly filled with fuel. In spite of the considerable slosh volume, the periodic deformation of the tank was barely noticeable. At the end of February 1961, the contracted number of specimens were ready. Following the standard acceptance inspection, the engineering flight tests began at Sharpe General Depot, Lathrop, California. Because of difficulties in deployment of test aircraft, the second phase of the program was discontinued at Sharpe General Depot and is still incomplete. A second engineering flight test was performed at Fort Ord, California, in July 1961 with only partial accomplishment. The completion of this phase of testing is now scheduled at the TMC Aviation Field Office at Edwards Air Force Base, California, and will be performed in the near future.

The destructive test series was started in June 1961 in combination with the simulated full-scale crash test series conducted by Aviation Crash Injury Research (AVCIR), Phoenix, Arizona, under the cognizance of USATRECOM. In this series of tests, torso seat tanks were placed in H-25 and H-13 helicopter seats. Part of the test is shown in the 8-millimeter color movie taken by the author. The ensuing tank failures in these tests can be attributed to the fact that the simulated crashes were "not survivable." Also it is a fact that the simulation of the crash conditions was imperfect, and the vertical vectors are thus exceedingly exaggerated. In discussions with AVCIR, it was agreed that the perfect simulation of a crash and crash environment would necessitate drone control of the test aircraft and realistic ground environment as a crash site (in the tests the crashes occurred on a hard-surface runway). Nevertheless, the results of the crash test could be evaluated in order to improve the design by minor modifications. This refers mainly to the protection against puncture.

The postcrash fire tests are scheduled for October 1961 at Aviation Crash Injury Research, Phoenix, Arizona. Two tank specimens are scheduled for this test. The dropability tests from limited altitudes will involve at least five specimens. The test plan for the dropability test aims to determine the maximum altitude of dropability of filled tanks without failure at impact. The drop site configuration will vary from smooth and soft sandy soil to wooded area or rockstrewn, torn ground.

TEST INSTRUMENTATION

Being field-type testing, the simplest instrumentation should be considered. It is not the scope of the whole program to strive for extreme accuracy. The major part of the answers can be obtained from flight instruments of test aircraft. Beyond this, recording accelerometers, strain gages, and high-speed movies (black and color) would give adequate information of dynamic conditions. Static conditions may be taken in still pictures. In crash fire tests, radiation pyrometers and electric timers may be used.

In crash tests, simple peak recording accelerometers can be devised with very little expense. The onset of acceleration can be evaluated from the analysis of high-speed movies in reference to timing.

The above statements are very general and indicate only the types of instrumentation. The actual instrumentation of test phases and individual test runs must be tailored to the test aircraft and the mission, and implemented occasionally.

Environmental testing is different from basic research in aim and character and should be handled correspondingly. In doing so, one may obtain the maximum of information in time and with the minimum of expenditure.